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STUDY OF DIMENSIONAL INTERRELATIONSHIPS
BETWEEN FACTORS AFFECTING EFFICIENT
HANDLING, STORAGE AND DISTRIBUTION

A THESIS

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SUMMARY

It is noted that any decision pertaining to one dimensional factor of the handling/storage/distribution system will affect many other dimensional factors throughout the whole system. For example, the decision of standardizing package base area has potential impact all the way down to the plant level, where unit loads ultimately will be assembled and warehoused. Likewise, the determination of carrier size will affect the size of unit load, and the size of unit load will have to be considered in the determination of the size of handling equipment, and vice versa.

This thesis presents a study of factors in the handling/storage/distribution cycle and their dimensional interrelationships. Its purpose is to establish guidelines to assist in selecting correct dimensions for items in the handling/storage/distribution system.

In studying the factors necessary for establishing dimensional relationships in the system, it was found that they may be classified as either quantitative or qualitative. At the same time, the characteristics of each factor could also be categorized as tangible, indeterminate or intangible, and identification of measurable characteristics of each quantitative factor is presented. The approach employed in selecting the correct dimensions begins with the inside dimensions of "standardized" carriers, i.e. highway trucks and railroad cars.

In this study, after the selection of factors specifically related to establishing "the" dimensions (see Chapter III and IV), concepts and equations are developed and examples applied to determining optimum sizes of unit loads, aisle widths, ceiling heights, etc. Several tables of dimensional sizes are recommended.

The results of this study not only demonstrate the importance of designing interrelationships between dimensional factors but also present an approach for solving the dimensional problem in the handling/storage/ distribution system. It also indicates that, in order to achieve a high degree of space utilization, a wide overall viewpoint should be taken, encompassing the whole system. The compatibility of international handling/storage/distribution systems must and can be worked out only if a unique dimensional standard system is first established.

CHAPTER I

INTRODUCTION

Each year billions of dollars are spent on handling, storage and distribution of various types of goods throughout the United States. Any effort or method that can be used in reducing these costs is highly desirable.

The ideal procedure in designing an integrated system for handling, storage and distribution would be to first design a good plant layout and establish the handling system. Unfortunately, in most cases, many items, such as the size of the carrier, have already been fixed by law and the handling unit or pallet must be designed to fit the limitations of existing inside carrier dimensions. This is true in storage operations as well as in the distribution system. Ordinarily, rail cars and trucks with relatively fixed dimensions already exist, and cans, packages or boxes must be related to the existing length, width and height restrictions.

First of all, this thesis attempts to list the factors to be considered in establishing dimensional relationships in the handling/storage/distribution system. Then the factors were classified as either quantitative or qualitative. Next, the quantifiable characteristics of major quantitative factors were identified.

Since this thesis is limited to the study of dimensional interrelationships between factors affecting efficiency, research attention from this point on must be focused on the dimensional factors only.

The objective of this thesis is to determine interrelationships between selected dimensional factors in order to provide a guide for choosing dimensions which will lower costs and increase profits.

CHAPTER II

LITERATURE SURVEY

A considerable search of available literature was made in an attempt to find previous work done on the study of dimensional interrelationships between factors affecting efficient handling/storage/distribution operations. Results show that there has been little or no research in this specific area, and further effort seems to be justified.

Most of the existing literature concerning this problem deals with the importance of material handling, storage or distribution. Some deals with all three at the same time. The search indicates that this specific problem has been studied only in a superficial way or to a certain level of interrelationship of the three. However, some worthwhile ideas and factors were drawn from these sources and were found helpful in this study.

The following material, quoted from Shubin and Madeheim (1) mentions the importance of storage, but provides no clue as to how the problem can be approached in a quantitative manner.

> Storage activities provide the following services to the plant; to receive all materials and supplies; to protect and reduce wastage of materials due to deterioration, theft, and breakage; upon authorization, issue materials in the required manner and quantities, and at the specified time; and to control temporary storage of work in process.
>
> Areas should be arranged in the floor plan to provide the maximum storage service at minimum cost. A good store's layout provides the following benefits: (1) efficient utilization of floor space devoted to

> storage, (2) quick availability of materials for manufacturing, (3) aids material control by facilitating physical turnover of materials and ease of taking physical inventory, (4) provides maximum flexibility of storage arrangement to permit changes and expansion of inventory at low cost.

The importance of materials handling was pointed out by John R. Immer (2).

> From the standpoint of the national economy, the cost involved in the movement and handling of materials assumes gigantic proportions. Within industry, the cost of moving materials from one workplace to another is often more than the processing cost itself. When the cost of the transportation of raw materials, of partly finished assemblies and parts, and of the finished product is added, the result if one of the largest single items of expense in the total economy.
>
> From the standpoint of the individual company, materials handling can be the millstone that plunges the firm into bankruptcy or retires it to a second-place position in the competitive picture. On the other hand, efficient materials handling may be the means of launching a new business or the sole means of continuing corporate existence in the face of restricted price levels and rising costs.

Also, in Roger N. Qunicoses' report (3), the importance of space utilization in transportation is stressed.

> In the study of transportation and materials handling, one of the principal problems is that of determining the most efficient, most transportable and least expensive (per unit weight or per unit volume) method(s) of shipping a produce or combination of products.

From these statements and others examined, stress is placed on the importance of conserving space in handling, storage or distribution, leading to the conclusion that it is reasonable to believe that any effort made toward utilizing existing space more efficiently will greatly reduce operating costs as well as capital investment.

The entire cycle of material handling, stroage and distribution activities has been outlined by Professor James M. Apple (4) as indicated in Table 2-1. Activities have been grouped sequentially under three different categories: handling, storage, and distribution, in order to show the need for finding their interrelationships. He has also identified and classified various factors that should be considered in making decisions relating to material flow, storage and distribution. These have been re-evaluated in terms of this research and a composite tabulation of factors is shown in Table 2-1 to 2-3 in the Appendix.

From these lists, one recognizes that factors have been gathered under individual subjects, but have not been organized to show the interrelationships between them. Nor has this data been classified as those which are quantitative or those which are qualitative. Nevertheless, these lists do provide a basis from which to initiate the classification process.

Table 2-1. MATERIAL HANDLING/STORAGE/DISTRIBUTION CYCLE*

Handling	Storage	Distribution
1. Packaging at vendor's plant	1. Materials storage	1. Common carrier transportation facilities
2. Packing at vendor's plant	2. Production acitivities	2. Materials issue and distribution
3. Loading at vendor's plant	3. Workplace materials handling	3. Inter-departmental handling
4. Common carrier transportation to user plants	4. In-process storage	4. Common carrier operations from plant
5. External plant transportation facilities	5. Finished goods warehousing	5. Intra-plant handling
6. Unloading		
7. Receiving operations		
8. Materials storage		
9. Materials issue and distribution		
10. Production activities		
11. Intra-departmental handling		
12. Workplace materials handling		
13. In-process storage		
14. Inter-departmental handling		
15. Service and auxiliary operations		
16. Quality control activities		
17. Packaging to customer specifications		
18. Packing to customer specifications		
19. Finished goods warehousing		
20. Stock picking		
21. Order assembly		
22. Loading operations		
23. Shipping operations		
24. Common carrier operations from plant		
25. Intra-plant handling		

*Adapted from Apple, James M., Fundamentals of Material Handling, Preliminary Edition, Georgia Tech, 1967, p. 2-2

CHAPTER III

DIMENSIONAL FACTORS AND THEIR INTERRELATIONSHIPS

The purpose of this chapter is to focus attention on the major dimensional factors and their interrelationships as they contribute to the effectiveness of material handling, storage and distribution. Through careful study, the composite tables in Appendix 2-1, 2-2, and 2-3 have been compiled, demonstrating that there are many aspects which need to be considered in planning an integrated system. The following tables present a tabulation of those factors, classified as to whether they are tangible, indeterminate or intangible, and they also identify each factor as to whether it is quantitative or qualitative.

Figure 3-1 shows the interrelationship between these three types of factors and their characteristics. The tangible factors are quantitative, the intangible factors qualitative, and the indeterminate factors may be either quantitative or qualitative.

Direct Factors

The first category of factors to be considered is that containing the tangible factors which are usually easily determined, readily accepted, and easily measured, as shown in Table 3-1. They may be defined as quantitative or readily measured in common units such as inches, feet, minutes, hours, etc. As mentioned previously, the tangible factors are the simplest to take into consideration in their effect on the handling/storage/distribution problem. Examples of tangible factors are

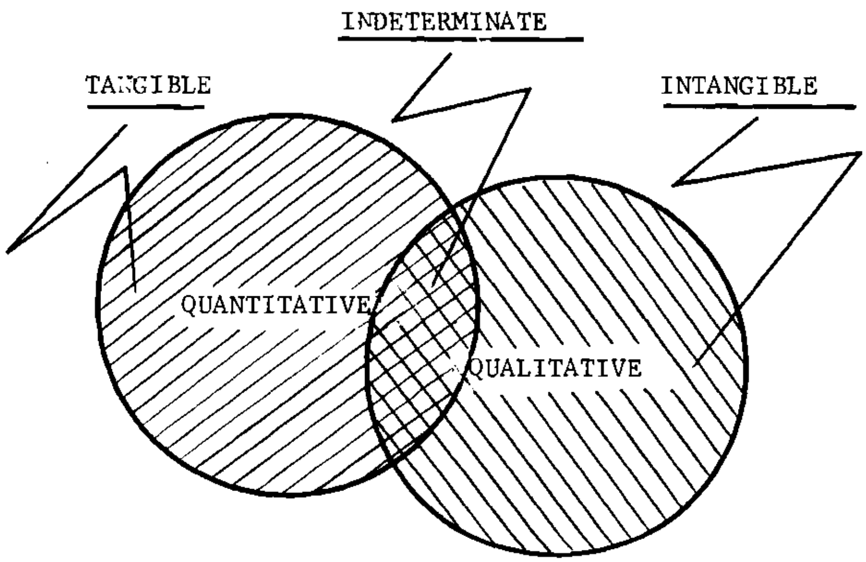

Figure 3-1. Factor Classification Diagram

Table 3-1

CHARACTERISTICS OF TANGIBLE FACTORS

RELATED TO HANDLING/STORAGE/DISTRIBUTION PROBLEMS

Material		Unit of Measure
1. quantity	QN*	lb., T.
2. density	QN	lb./cu.-ft.
3. number of different parts	QN	1, 2, 3, ...
Move		
1. speed	QN	ft./sec.,ft./min.,mile/hr.
2. volume	QN	cu.-ft.
3. distance	QN	in., ft., mile
4. frequency	QN	no./time
5. rate	QN	lb./min.,T./hr.
6. area	QN	sq.-ft.
7. range	QN	ft., mile
8. load/unload level	QN	in., ft.
9. movement level	QN	in., ft.
Process and Operation		
1. reliability	QN	%
2. number of operations	QN	1, 2, 3, ...
3. number of sub-assemblies	QN	1, 2, 3, ...
4. number of different parts	QN	1, 2, 3, ...
Products Container, Packing Container and Unit Load		
1. length	QN	in., ft.
2. width	QN	in., ft.
3. height	QN	in., ft.
4. diameter	QN	in., ft.
5. weight	QN	lb., T.
6. items/load	QN	no. items/load
7. tare	QN	lb., T.
8. capacity	QN	lb., T.

*NOTE: QN = Quantitative and QL = Qualitative

Carrier		Unit of Measure
1. length	QN	in., ft.
2. width	QN	in., ft.
3. height	QN	in., ft.
4. capacity	QN	lb., T.
5. operation clearance	QN	in.
6. structural design	QN	lb./sq.-ft., T./sq.-ft.
Storage Space		
1. column spacing	QN	ft.
2. aisle width	QN	in., ft.
3. clear height	QN	ft.
4. plant size	QN	cu.-ft.
5. cost of floor space	QN	$/sq.-ft.
6. number of floors	QN	1, 2, 3, ...
7. space requirements	QN	cu.-ft.
8. space available	QN	cu.-ft.
9. total volume of storage	QN	cu.-ft.
10. storage time	QN	day, week, month
11. floor load capacity	QN	lb./sq.-ft., T./sq.-ft.
12. overhead load capacity	QN	lb./sq.-ft., T./sq.-ft.
13. size of door	QN	in., ft.
14. load on the roof	QN	lb./sq.-ft., T./sq.-ft.
15. load on the trusses, joists, etc.	QN	lb./sq.-ft., T./sq.-ft.
16. size of elevator	QN	in., ft.
Storage Equipment		
1. dimension of storage slot	QN	ft.
2. capacity of storage slot	QN	lb., T.
3. clearance between load	QN	in., ft.
4. total volume of storage	QN	cu.-ft.
5. working headroom	QN	in., ft.
6. number of loads in depth from the aisle	QN	1, 2, 3, ...

Storage Equipment (Continued)

7. number of loads facing the aisle	QN	1, 2, 3, ...
8. storage requirements	QN	cu.-ft.
Handling Equipment		
1. dimension	QN	in., ft.
2. speed	QN	ft./min., mile/hr.
3. capacity	QN	lb., T.
4. horse power	QN	hp.
5. turning radius	QN	in., ft.
6. retracted height	QN	ft.
7. maximum speed	QN	ft./min., mile/hr.
8. stacking heights	QN	ft.
9. load center	QN	in.-lbs., ft.-lbs.
10. performance of handling	QN	%

the dimensions of product containers, the size of truck trailers, the total volume of storage space, the quantity of material and the ceiling height of buildings.

Indeterminate Factors

The second category of factors to be examined is that classified as indeterminate, which are characterized as imponderable, estimated or "guessed" (Table 3-2). They are not as easily evaluated or determined but can be estimated. Usually, the measurement of this kind of factor cannot be expressed in common units, such as pounds, inches or minutes. Examples are the flamability of material, the pattern of movement, the shape of buildings and the type of handling equipment. There is no way of expressing the shape of a building in inches or minutes. Such lack of quantitative definition in no way alters or minimizes the importance of indeterminate factors.

Intangible Factors

The last category of factors to be considered when facing a handling/storage/distribution problem is that of intangible factors. Table 3-3 lists the intangible factors that are not easily seen or measured, and must be evaluated on a basis of judgement. Their effect on the handling/storage/distribution problem may be substantial, yet the most difficult to take into consideration. As has been stated, "They are extremely important, and in many cases, may outweigh or override the more easily determined items." (4).

Since the object of this thesis is the study of dimensional inter-relationships between factors affecting efficiency, attention from this

Table 3-2

CHARACTERISTICS OF INDETERMINATE FACTORS
RELATED TO HANDLING/STORAGE/DISTRIBUTION PROBLEMS

Material		Unit of Measure
1. flowability	QN	Flow Function (FF)
2. viscosity	QN	Coefficient of Viscosity
3. compressibility	QN	Coefficient of Compressi-bility
4. acidity/alkalinity	QN	pH value
5. moisture content	QN	Weight of water evaporated
6. abrasiveness	QN	Abrasive index
7. elevated temperature	QN	F
8. particle hardness	QN	Mohs scale and Kroop method
9. size	QN	No. of sieve
10. cohesiveness	QN	Shear stress due to cohesion
11. dusty	QN	% weight dropped
12. corrosiveness	QN	pH value
13. friability	QL	
14. shrinkage	QL	
15. evaporation	QL	
16. toxicity	QL	
17. flamability	QL	
18. light sensitivity	QL	
19. interlocks, mats, agglomerates	QL	
20. generates static electricity	QL	
21. particle shape	QL	
22. physical condition	QL	
23. explosiveness	QL	
24. contaminable	QL	
25. fragile	QL	
26. sturdy	QL	
27. perishability	QL	

Move

1. scope	QL
2. sequence	QL
3. traffic type	QL
4. traffic direction	QL
5. operations in transit	QL
6. cross-traffic	QL
7. origin and destination	QL
8. movement of personnel	QL
9. location	QL
10. course	QL

Process and Operation

1. type	QL
2. interrelationships	QL
3. specific requirements	QL
4. operation sequence	QL
5. product vs. process layout	QL
6. production control	QL
7. possibility of performing during move	QL

Product Container, Packing Container and Unit Load

1. type	QL
2. shape	QL
3. characteristics	QL
4. stability	QL
5. construction	QL
6. disposal of container	QL
7. pattern	QL

Carrier

1. type	QL
2. shape	QL
3. characteristics	QL
4. construction material	QL

Storage Space	
1. shape of building	QL
2. type of building	QL
3. type of construction	QL
4. location of doors	QL
5. location of columns	QL
6. location of elevator	QL
7. type of columns	QL
8. type of elevator	QL
9. fire regulations	QL
10. type of aisle	QL
11. location of aisle	QL
12. building congestion	QL
13. accessibility to equipment	QL
14. location of receiving and shipping	QL
15. congested areas	QL
16. ramps	QL
17. construction materials	QL
Storage Equipment	
1. type of equipment	QL
2. working conditions	QL
3. shape of equipment	QL
4. storage method	QL
5. handling method	QL
6. environmental requirements	QL
7. fixed/floating slot	QL
8. supervisory requirements	QL
Handling Equipment	
1. desired characteristics	QL
2. type	QL
3. operator position	QL
4. motive power	QL
5. auxiliary equipment	QL
6. travel plan	QL

	Handling Equipment (Continued)	
7.	supplementary load/unload	QL
8.	take-up	QL
9.	discharge method	QL
10.	feed type	QL
11.	idler type	QL
12.	tire type	QL
13.	belt direction	QL
14.	support	QL

Table 3-3

CHARACTERISTICS OF INTANGIBLE FACTORS
RELATED TO HANDLING/STORAGE/DISTRIBUTION PROBLEMS

1. durability of equipment	QL
2. compatibility of equipment	QL
3. standardization of equipment and components	QL
4. flexibility	QL
5. adaptability	QL
6. safety	QL
7. obsolescence	QL
8. reputation	QL
9. availability of equipment	QL
10. possible damage of materials	QL
11. possible pilferage in transit and storage	QL
12. possible reduction in insurance areas	QL
13. financial policy	QL
14. labor relations aspects	QL
15. effect on morale	QL
16. plans for expansion	QL
17. improved customer service	QL
18. pride in installation	QL
19. possible use of gravity	QL
20. possible alternatives	QL
21. depreciation policy	QL

point on must be focused on the dimensional factors. Figure 3-2 shows those items that have dimensional characteristics in the handling/storage/distribution cycle, such as product containers, packing containers, unit loads, carriers, handling equipment, storage equipment and storage space. The dimensional aspects of all of these elements affect each other.

It is necessary to demonstrate the degree of importance of the interrelationships between these factors. Table 3-1, 3-2 and 3-3 present most factors, whether dimensional or non-dimensional, and are used as sources for selecting the dimensional factors. From them, Figure 3-3, which shows the interrelationship between selected quantitative factors affecting handling/storage/distribution problems is developed. It shows the degree of importance of the interrelationships between the factors, which are defined as very important, important, or not important. In the square at the intersection of each pair of factors is recorded a letter to represent the degree of relationship. For example, Item 18, the turning radius, has a very important relationship with aisle width, Item 23. Therefore, a V is entered in the square.

Of course, the person determining the degree of importance of dimensional interrelationships must be highly experienced in this specific field in order to make correct judgments. Even so, the results, as shown in Table 3-4, may vary slightly with each person performing the assignment. However, this does not affect the usefulness of the table. The table not only attracts attention, but also quickly identifies those factors which will have the greatest effect on the system and provides assistance in dealing with the specific problem. In other words, it

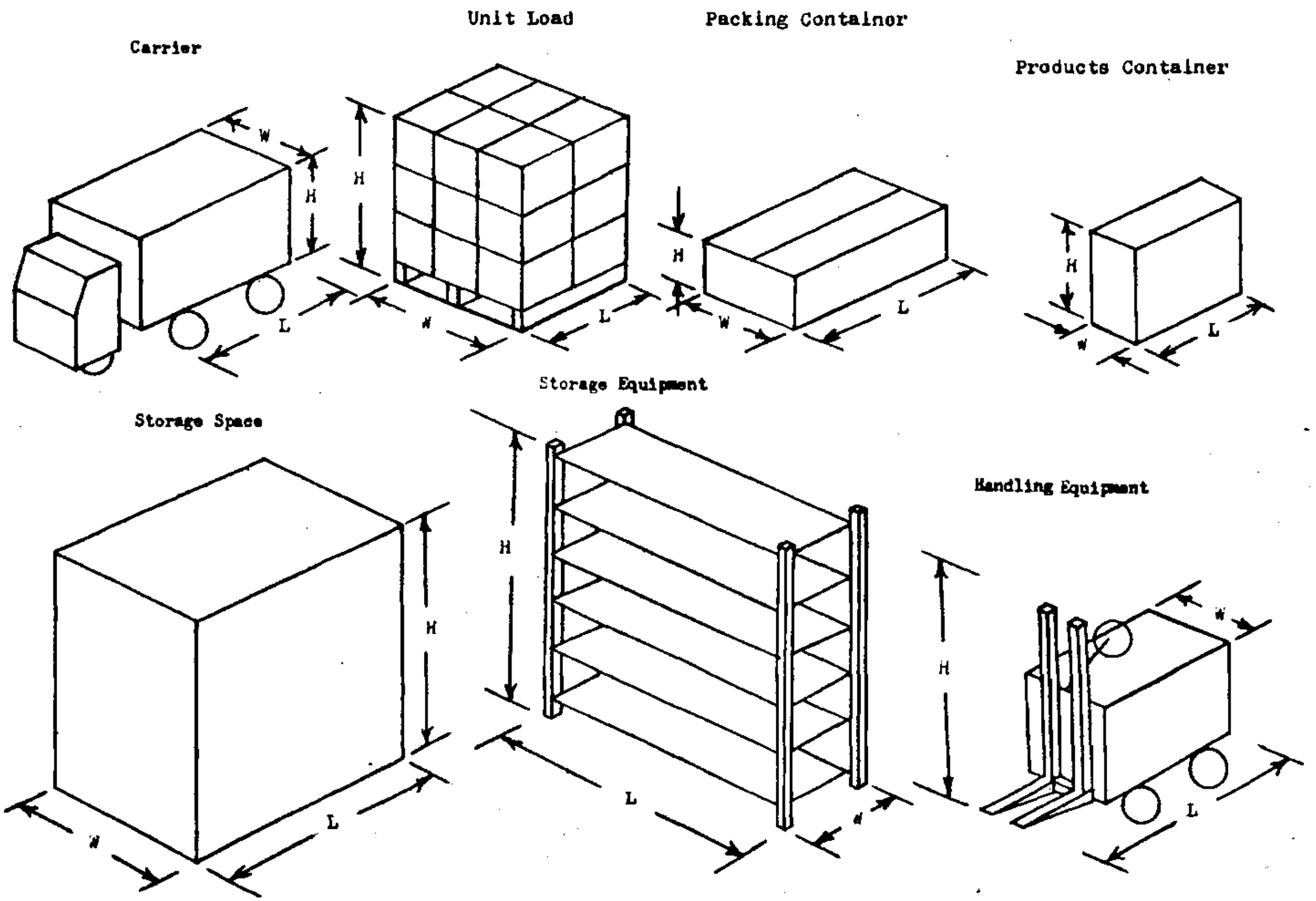

Figure 3-2. Dimensional Factors of Handling/Storage/Distribution

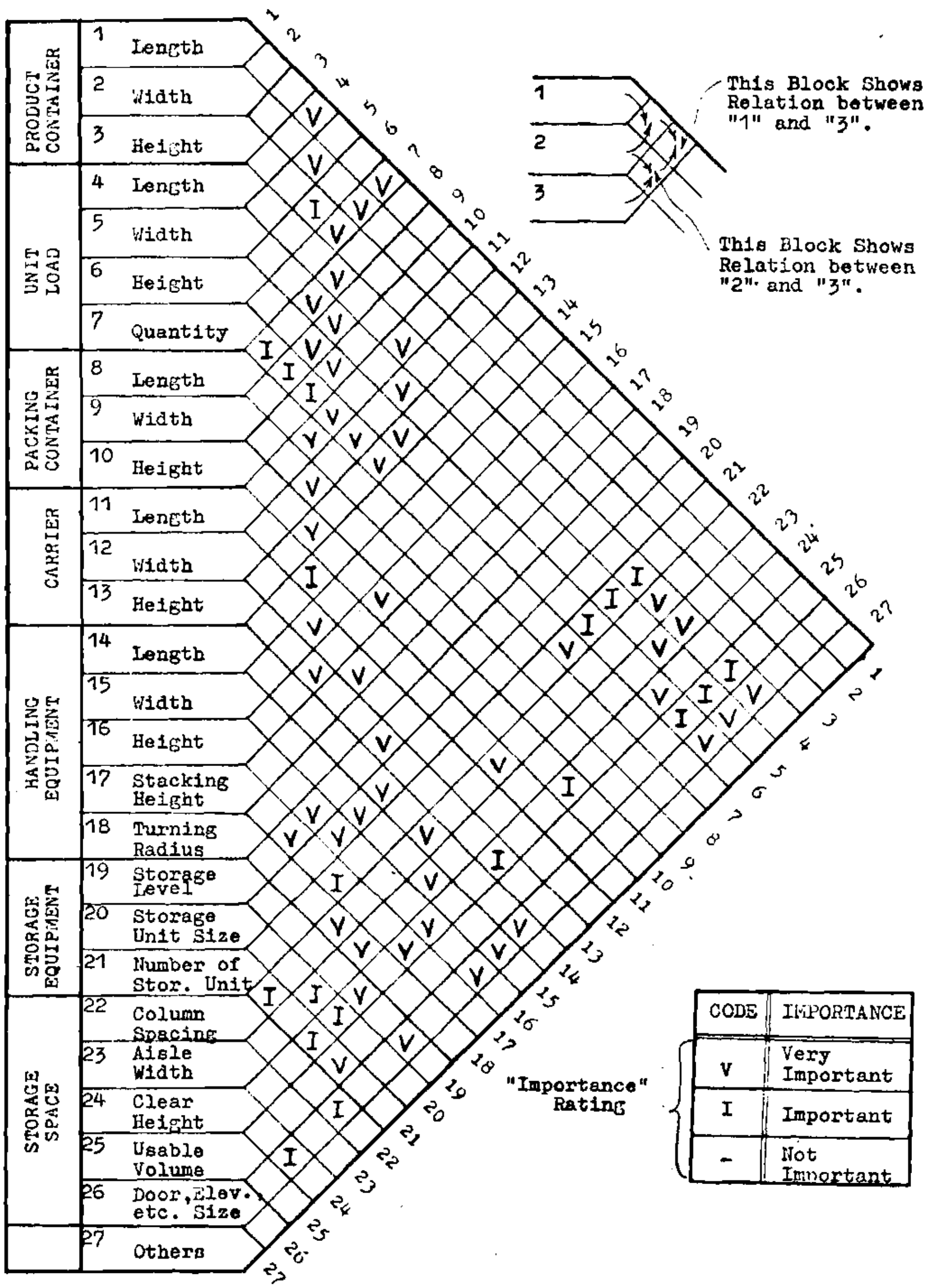

Figure 3-3. Dimensional Interrelationship Chart

Items	NO.	Dimensional Factors	DEGREE OF IMPORTANCE	
			Very Important	Important
PRODUCT CONTAINER	1	Length	4,7	
	2	Width	5,7	
	3	Height	7	6
UNIT LOAD	4	Length	1,8,11,22,23, 26	21,25
	5	Width	2,8,9,12,23, 26	21,25
	6	Height	9,10,13,24,26	3,21,25
	7	Quantity	1,2,3,11,12, 13,21	8,9,10
PACKING CONTAINER	8	Length	4,5,11	7
	9	Width	5,6,12	7
	10	Height	6,13,16	7,24
CARRIER	11	Length	4,7,8,22	14
	12	Width	5,7,9,15,17	
	13	Height	6,7,10,16,19	24
HANDLING EQUIPMENT	14	Length	20,22,26	11
	15	Width	12,20,23,26	
	16	Height	10,13,19,20 24,26	
	17	Stacking Height	12,19,24	21
	18	Turning Radius	22,23	
STORAGE EQUIPMENT	19	Storage Level	13,16,17,24, 26	
	20	Storage Unit Size	14,15,16	23,24
	21	Number of Storage Units	7,25	4,5,6,17,22,24
STORAGE SPACE	22	Column Spacing	4,11,14,18	21,26
	23	Aisle Width	4,5,15,18	20
	24	Clear Height	6,16,17,19	10,13,20,21,26
	25	Usable Volume	21	4,5,6
	26	Door, Elev., etc. Size	4,5,6,14,15, 16,19	22,24

Table 3-4. Worksheet of Relationship Importance between Dimensional Factors

draws immediate attention to those factors that are most important. For example, when the decision on proper aisle width is needed, Item 23 in Table 3-4 indicates the factor-importance for the length and width of the unit load and the width and turning radius of handling equipment, and indicates that they are the major factors affecting aisle width.

CHAPTER IV

A GUIDE FOR CHOOSING THE CORRECT DIMENSIONS

The most reasonable approach to determining the correct dimensions for unit loads, handling equipment, etc., is to base them on carrier dimensions that have already been established and limited by law.

F. V. Schultz (5) has stated, ". . . that dimensioning of transport packaging should begin with the inside dimensions of the already internationally standardized (8 x 8 x 20 - 30 - 40 ft), intermodal container. From this foundation, a family of compatible, unit-load sizes could then be developed to fully utilize the floor space (and cube) of the container and provide efficient material handling."

In Georgia, for example, the maximum allowable height for a truck trailer is 13'6"; the width is usually less than or equal to 8'. The sequency for selecting the correct dimensions will be presented in the format suggested in Figure 4-1. Thus, first of all, it is desired to find the "ideal" sizes for unit loads, based on carrier dimensions.

Carrier and Unit Load

In this study, the term carrier refers to a highway trailer van or railway freight car, but the approach can be expanded to cover air and sea freight problems as well.

Figure 4-2 indicates the dimensional aspects a highway trailer van, and assumes that the certain dimensions of the carrier body are fixed by law. It is also assumed that the pallet is a four-way pallet with the

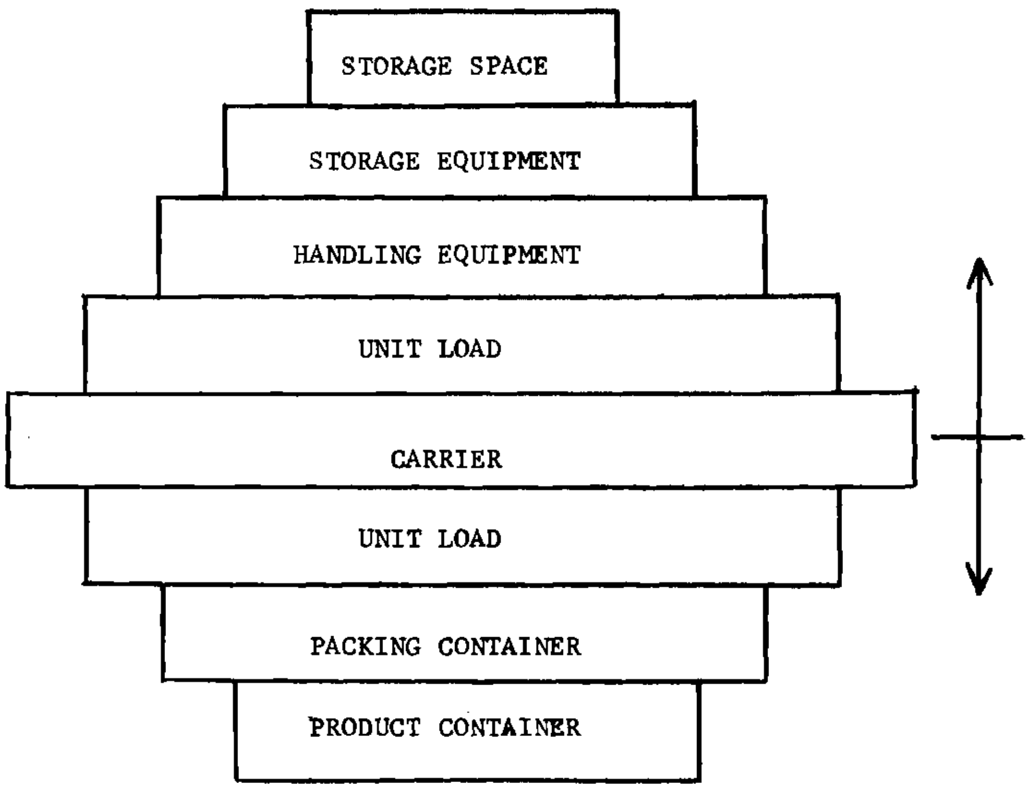

Figure 4-1. An Approach to Establishing Dimensions

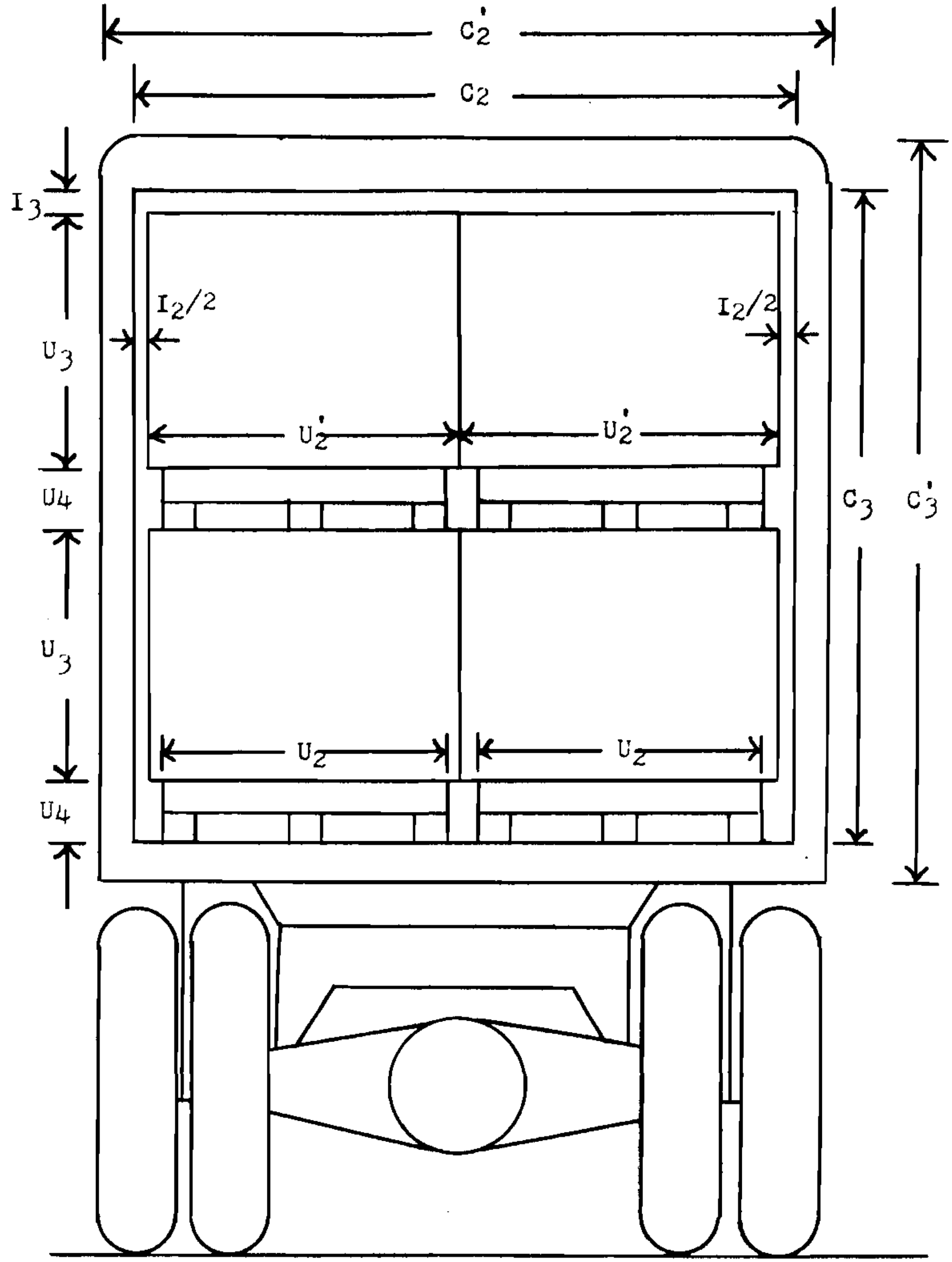

Figure 4-2. Highway Trailer Van Dimensional Concept

width facing the rear of the trailer. It will be noted that many dimensional factors in the following list are (or are directly related to) those marked V or I in the Dimensional Interrelationship Chart (Figure 3-3).

C_1 = inside length of trailer

C_1' = outside length of trailer

C_2 = inside width of trailer

C_2' = outside width of trailer

C_3 = inside height of trailer

C_3' = outside height of trailer

C_5 = inside usable height of car

C_5' = outside height of car

C_6 = inside width of car

C_6' = outside width of car

I_2 = allow clearance for material handling in width

I_3 = allow clearance for material handling in height

J = overhang of unit load

M_2 = number of unit loads in length (car)

M_3 = number of unit loads in height (car)

N_1 = number of unit loads in length (trailer)

N_2 = number of unit loads in width (trailer)

N_3 = number of unit loads in height

U_1 = length of pallet

U_1' = overall unit load length

U_2 = width of pallet

U_2' = overall unit load width

U_3 = height of commodity on pallet

U_3' = overall unit load height

U_4 = thickness of pallet

Since the problem to be dealt with here is dimensions, no consideration will be given to the density of a load or the capacity of a facility.

From Figure 4-2, the overall unit load width could be expressed as follows:

$$U_2' = \frac{C_2 - I_2}{N_2} \tag{1}$$

and

$$U_2 = U_2' - J = \frac{C_2 - I_2 - N_2 J}{N_2} \tag{2}$$

It may also be seen from Figure 4-2, that

$$U_3' = \frac{C_3 - I_3}{N_3} \tag{3}$$

$$U_3 = U_3' - U_4 = \frac{C_3 - I_3 - N_3 U_4}{N_3} \tag{4}$$

In considering the railroad car, (Figure 4-3), it was assumed that the pallet is a four-way pallet with the length facing rear. In this case, the ideal length of the pallet can be indicated as:

$$U_1' = \frac{C_6 - I_2}{M_2} \tag{5}$$

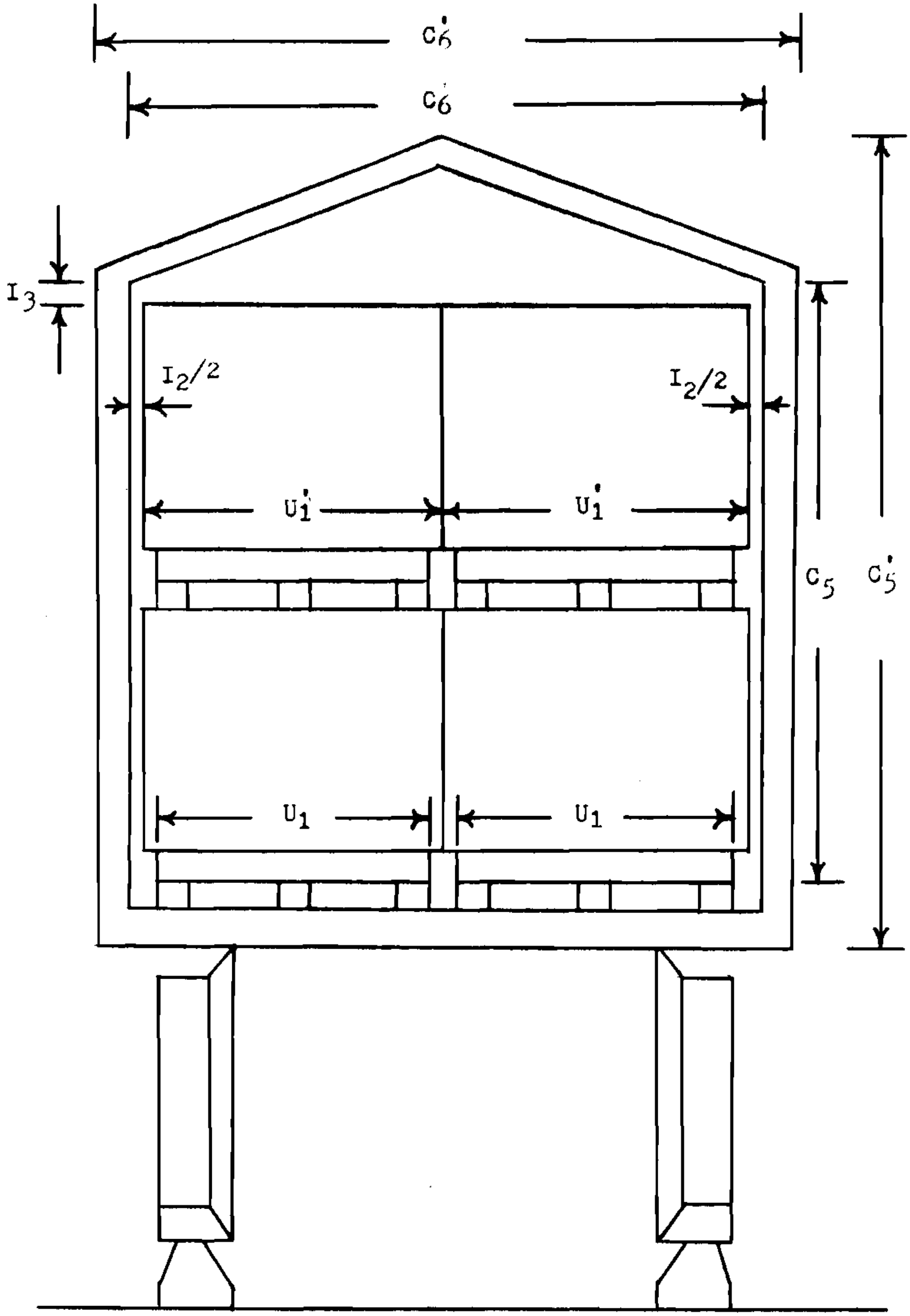

Figure 4-3. Railway Freight Car Dimensional Concept

$$U_1 = U_1' - J = \frac{C_6 - I_2 - M_2J}{M_2} \tag{6}$$

and

$$U_3' = \frac{C_5 - I_3}{M_3} \tag{7}$$

$$U_3 = U_3' - U_4 = \frac{C_5 - I_3 - M_3U_4}{M_3} \tag{8}$$

To illustrate, several example are given below for the formulae which have been established thus far. In the United States, both external width and height of a truck trailer are stated as 96 inches (2438mm.). If one assumes that the minimum gross interior width and height of a truck trailer are C_2 = 92 inches (2337mm) and C_3 = 92 inches (2337mm) (6), while $N_2 = N_3 = 2$, $I_2 = I_3 = 2''$, $J = 3''$ and $U_4 = 5''$, then equation (1) and (2) yield:

$$U_2' = \frac{C_2 - I_2}{N_2} = \frac{92'' - 2''}{2} = 45'' \text{ (1140mm)}$$

and

$$U_2 = U_2' - J = 45'' - 3'' = 42'' \text{ (1060mm)}$$

Equations (3) and (4) yield:

$$U_3' = \frac{C_3 - I_3}{N_3} = \frac{92'' - 2''}{2} = 45'' \text{ (1140mm)}$$

$$U_3 = U_3' - U_4 = 45'' - 5'' = 40'' \text{ (1000mm)}$$

Also, the interior minimum gross width and height of a railway freight car are usually stated as $C_6 = 110''$ (2794mm) and $C_5 = 125''$ (3175mm). If $I_2 = 2''$, $M_2 = 2$, $J = 4''$ in equation (5) and (6), then

$$U_1' = \frac{C_6 - I_2}{M_2} = \frac{110'' - 2''}{2} = 54'' \quad (1370\text{mm})$$

$$U_1 = U_1' - J = 54'' - 4'' = 50'' \ (1270\text{mm})$$

if $M_2 = 3$ and $J = 2''$, then

$$U_1' = \frac{C_6 - I_2}{M_2} = \frac{110'' - 2''}{3} = 36'' \ (900\text{mm})$$

$$U_1 = U_1' - J = 36'' - 2'' = 34'' \ (860\text{mm})$$

In equation (7) and (8), let M_3, $I_3 = 5''$ and $U_4 = 5''$, which then yields

$$U_3' = \frac{C_5 - I_3}{M_3} = \frac{125'' - 5''}{2} = 60'' \ (1500\text{mm})$$

$$U_3 = U_3' - U_4 = 60'' - 5'' = 55'' \ (1400\text{mm})$$

if $M_3 = 3$, then

$$U_3' = \frac{C_5 - I_3}{M_3} = \frac{125'' - 5''}{3} = 40'' \ (1000\text{mm})$$

$$U_3 = U_3' - U_4 = 40'' - 5'' = 35'' \ (890\text{mm})$$

Using equations (1) to (8) as above, all possible (ideal) standard unit load sizes can be obtained for use in designing as future transportation modes. Table 4-1 presents eight different unit load sizes for either highway truck or railway car, which after careful examination can be simplified as shown in Table 4-2. For example, any standardized unit load with code I-1-H-2 has size 30" x 36" x 30" (760 x 900 x 760 mm) or I-3-R-2 has size 30" x 54" x 60" (760 x 1400 x 1500 mm). Here the

Table 4-1. POSSIBLE STANDARD UNIT LOAD SIZES

HIGHWAY TRUCK TRAILER VAN						RAILWAY FREIGHT CAR					
Code	N_2	M_2	N_3	Inch Sys. LxWxH	Metric Sys. LxWxH	Code	N_2	M_2	M_3	Inch Sys. LxWxH	Metric Sys. LxWxH
H-1	2	2	2	45x54x45	1140x1370x1140	R-1	2	2	2	45x54x60	1140x1370x1500
H-2	3	2	2	30x54x45	760x1370x1140	R-2	3	2	2	30x54x60	760x1370x1500
H-3	2	3	2	45x36x45	1140x900x1140	R-3	2	3	2	45x36x60	1140x900x1500
H-4	2	2	3	45x54x30	1140x1370x760	R-4	2	2	3	45x54x40	1140x1400x1000
H-5	3	3	3	30x36x30	760x900x760	R-5	3	3	3	30x36x40	760x900x1000
H-6	2	3	3	45x36x30	1140x900x760	R-6	2	3	3	45x36x40	1140x900x1000
H-7	3	2	3	30x54x30	760x1370x760	R-7	3	2	3	30x54x40	760x1370x1000
H-8	3	3	2	30x36x45	760x900x1140	R-8	3	3	2	30x36x60	760x900x1500

NOTE: L - Length; W - Width; H - Height

Table 4-2. STANDARDIZED UNIT LOAD SIZE

Code	Inch Sys.		Metric Sys.		Height							
					Inch system				Metric system			
	L	W	L	W	H-1	R-1	H-2	R-2	H-1	R-1	H-2	R-2
I-1	30	36	760	900	30	40	45	60	760	1000	1140	1500
I-2	45	36	1140	900	30	40	45	60	760	1000	1140	1500
I-3	30	54	760	1370	30	40	45	60	760	1000	1140	1500
I-4	45	54	1140	1370	30	40	45	60	760	1000	1140	1500

Note:

L = Length, W = Width

H-1 or H-2 -- Unit load height in highway truck

R-1 or R-2 -- Unit load height in railway car density of unit load and the capacity of pallet will be the major factors in determining the selection of the height of the unit load. As stated above, such non-dimensional factors are not to be considered in this study.

Applying the Approach to Handling Equipment as Related to Storage Equipment and Storage Space

The next items to be discussed are the potential dimensions of handling equipment, storage equipment and storage space. Since standard unit load sizes have been previously established, it is possible to use these dimensions for continuing the study.

In working on a related problem, Thornton (7), who was primarily concerned with space efficiency, developed some concepts or assumptions which will be adapted to this study. Thornton placed some restrictions on the movement of the unit load. In Figures 4-4, 4-5, and 4-6, a right angle stacking aisle width with no clearance between the unit loads has been assumed. The fork lift truck and unit load are unable to turn until the end of the load is withdrawn completely from the storage area into the aisle.

In Figure 4-4 (8), for a rear wheel steer truck with narrow loads ($U_2' \leq 2E_1$), the aisle width may be defined as follows:

$$A = E_4 + D + U_1' + H \qquad (9)$$

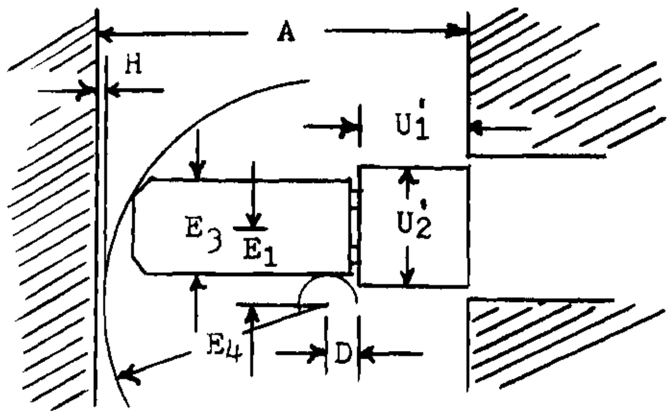

Figure 4-4 Rear Wheel, Steer with Narrow Loads: $(U_2 \leq 2E_1)$

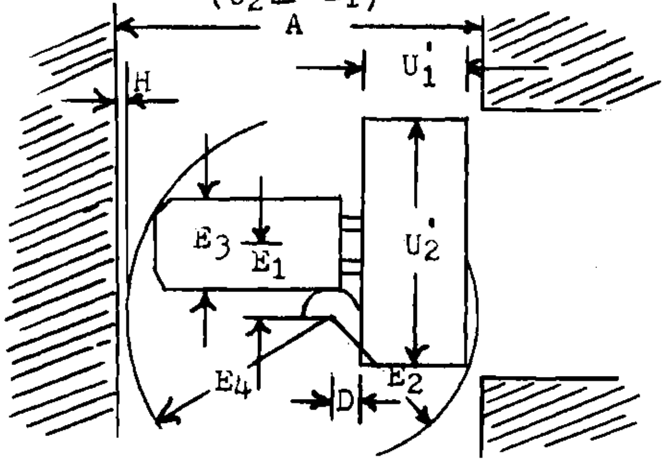

Figure 4-5 Rear Wheel Steer with Medium Width Loads: $(U_2' > 2E_1$ and $U_2' \leq 2(E_4 - E_1))$

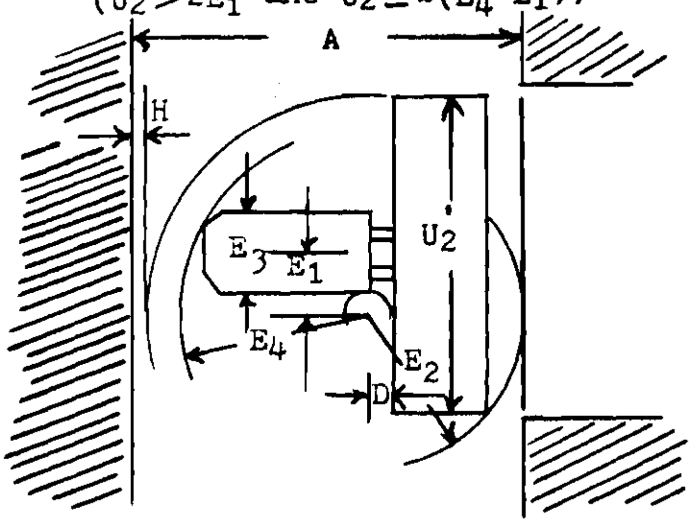

Figure 4-6 Rear Wheel Steer with Wide Loads: $(U_2' > 2E_1$ and $U_2 > 2(E_4 - E_1))$

with

A = min. aisle width for right stacking

D = longitudinal distance from rear face of load to centerline drive axle or to center of turn

E_1 = distance from centerline of truck to center of turn

E_2 = distance from center of turn to rear inside load corner

E_3 = overall truck width

E_4 = outside turning radius

H = operating clearance in aisle

U_1' = overall load length

U_2' = overall load width

In Figure 4-5, rear wheel steer with medium width loads, the aisle width may be expressed as

$$E_2 = \sqrt{(D + U_1')^2 + (\tfrac{1}{2} U_2' - E_1)^2} \tag{10}$$

$$A = E_4 + E_2 + H \tag{11}$$

so

$$A = E_4 + \sqrt{(D + U_1')^2 + (\tfrac{1}{2} U_2' - E_1)^2} + H \tag{12}$$

In Figure 4-6, rear wheel steer with wide loads, the aisle width could be derived as

$$E_2 = \sqrt{(D + U_1')^2 + (\tfrac{1}{2} U_2' + E_1)^2} \tag{13}$$

$$A = \tfrac{1}{2} U_2' + E_1 + E_2 + H \tag{14}$$

$$A = \tfrac{1}{2} U_2' + E_1 + \sqrt{(D + U')^2 + (\tfrac{1}{2} U_2' + E_1)^2} + H \tag{15}$$

If one substitutes equation (5) in equation (9), the latter is changed as follows:

$$A = E_4 + D + \frac{C_6 - I_2}{M_2} + H \tag{16}$$

Substitution of equations (1) and (5) in equation (12) yields

$$A = E_4 + \sqrt{\left(D + \frac{C_6 - I_2}{M_2}\right)^2 + \left(\frac{C_2 - I_2}{2N_2} - E_1\right)^2} + H \tag{17}$$

Finally, substitution of equations (1) and (5) in equation (15) yields

$$A = \frac{C_2 - I_2}{2N_2} + E_1 + \sqrt{\left(D + \frac{C_6 - I_2}{M_2}\right)^2 + \left(\frac{C_2 - I_2}{2N_2} - E_1\right)} + H \tag{18}$$

Examination of the above equations indicate the following:

(1) In equation (9), if E_4, D and H are constant, then A increases as U_1' increases. In equation (16), if C_6 and I_2 are kept unchanged, then A decreases as M_2 increases.

(2) In equation (12) and (15), A increases monotonically as U_1' and U_2' increase. In equations (17) and (18), if C_6 and I_2 are kept unchanged, then A decreases as either M_2 or N_2 increase.

In Figure 4-7, it may be assumed that $U_2' \leq 2E_1$. Then the aisle width is the sum of unit load and fork truck parameters as stated in equation (9)

$$A = E_4 + D + U_1' + H$$

Let

R_4 = lateral clearance between unit loads on storage racks

G_d = number of loads in depth from the aisle

G_w = number of loads facing the aisle

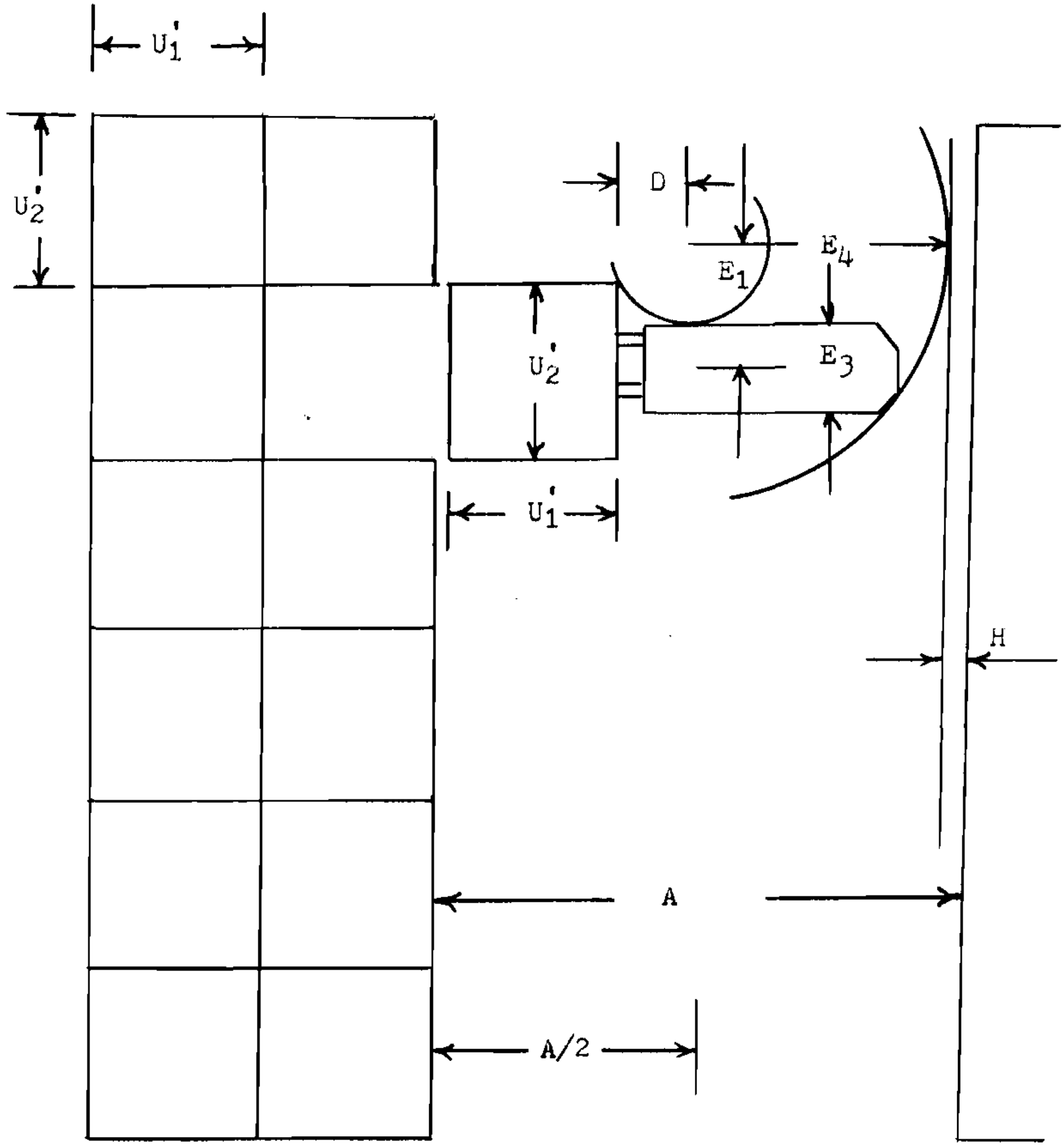

Figure 4-7. Right Angle Storage

It can be seen that the storage racks in which the loads rest contain G unit loads. Since it is assumed that there is no clearance between unit loads, then the area occupied by the G loads may be expressed as

$$\text{Area Utilized} = U_1' \, U_2' \, G_d \, G_w$$

Assuming that each level of the storage rack contains two rows of unit loads back-to-back, the total relevant area is characterized as the area occupied by the pallets plus one-half the area of the aisle on which the unit loads face.

This may be expressed as (7)

$$\text{Total Area} = \left[G_w U_2' + R_4(G_w - 1)\right] \left(G_d U_1' - \frac{A}{2}\right)$$

$$= \left[G_w U_2' + R_4(G_w - 1)\right] \left(G_d U_1' + \frac{E_4 + D + U_1' + H}{2}\right)$$

The equation for the efficiency of utilization of area may be expressed as

$$E_{ff} = \frac{\text{Area Utilized}}{\text{Total Area}} \times 100\%$$

and

$$E_{ff} = \frac{100 \, U_1' \, U_2' \, G_d \, G_w}{\left[G_w U_2' + R_4(G_w - 1)\right]\left(G_d U_1' + \frac{E_4 + D + U_1' + H}{2}\right)} \%$$

Now, let R_4 - 0 as assumed before, and simplify the equation to give

$$E_{ff} = \frac{200 \, G_d \, U_1'}{(2G_d + 1) \, U_1' + (E_4 + D + H)} \% \qquad (19)$$

If we substitute equation (5) into equation (19), then it yields

$$E_{ff} = \frac{200\ G_d\ \dfrac{C_6 - I_2}{M_2}}{(2G_d + 1)\dfrac{C_6 - I_2}{M_2} + (E_4 + D + H)}\ \%$$

$$= \frac{200\ G_d\ (C_6 - I_2)}{(2G_d + 1)(C_6 - I_6) + (E_4 + D + H)\ M_2}\ \% \qquad (20)$$

Examination of above equations indicates the following:

(1) In equation (19), E_{ff} is independent of U_2' and G_w. In equation (20), E_{ff} is independent of N_2 and G_w.

(2) In equation (19), E_{ff} increases monotonically as G_d and U_1' increase. In equation (20), if C_6 and I_2 are constant, then E_{ff} increases as G_d increases and decreases as M_2 increases.

(3) E_{ff} decreases as the lift truck parameter $(E_4 + D + H)$ increases.

In order to assist the engineer, Tables 4-3 and 4-4 have been prepared which should cover the average ranges. The following example illustrates these computations, covering four sizes of unit loads and one size of fork lift truck. The range of each of the variables is shown as follows:

U_1' = 30", 36", 45", 54"

G_d = 1, 2, 3, ..., 10

H = 6"

E_r = 60"

D = 14"

$T = E_4 + D + H = 60 + 14 + 6 = 80"$ (8)

The sum of the variables E_4, D and H, is denoted by T. If one selects a unit load with length, $U_1' = 45''$; a fork truck with $T = 80''$; and depth of unit loads, $G_d = 1$, by using equation (19), the following equation can be obtained.

$$E_{ff} = \frac{200(1)45}{[2(1) + 1]45 + 80} = 41.6\%$$

The aisle width is of considerable importance in conjunction with floor space efficiency; therefore, using equation (9) for the aisle width,

$$A = U_1' + (E_4 + D + H) = U_1' + T$$

$$A = 45 + 60 + 14 + 6 = 125''$$

A summary of the efficiencies for space utilization is listed in Table 4-3, and aisle width in Table 4-4.

Applying the Approach to the Unit Load in Relation to Storage Equipment and Storage Space

Figure 4-8 indicates the concept of storage equipment for unit loads. Note that loads stored on the top are used for reserve while only the lower two slots are usually used for order picking.

Before proceeding to the dimensional aspects of the storage equipment, it is necessary to define some of the terms (9):

Working Headroom: the distance from the floor to a point twelve inches or more below the lowest overhead obstructions. Working headroom is usually controlled to avoid coming into contact with overhead obstructions in the storage area and to maintain the unit clearances required by local fire regulations or ordinances.

Table 4-3. Floor Space Utilization Efficiency in Per Cent when T = 80"

G_d \ U_1'	30"	36"	45"	54"
1	35.3	38.3	41.9	44.6
2	52.2	55.4	59.0	61.7
3	62.1	65.1	68.4	70.7
4	68.4	71.3	74.2	76.3
5	73.2	75.6	78.3	80.1
6	76.6	78.8	81.2	82.9
7	79.2	81.3	83.4	84.9
8	81.4	83.2	85.2	86.6
9	83.1	84.8	86.6	87.9
10	84.5	86.1	87.8	89.0

Table 4-4. Aisle Width (Inches)

U_1' \ T	75"	80"	85"	90"	95"	100"
30"	105	110	115	120	125	130
36"	111	116	121	126	131	136
45"	120	125	130	135	140	145
54"	129	134	139	144	149	154

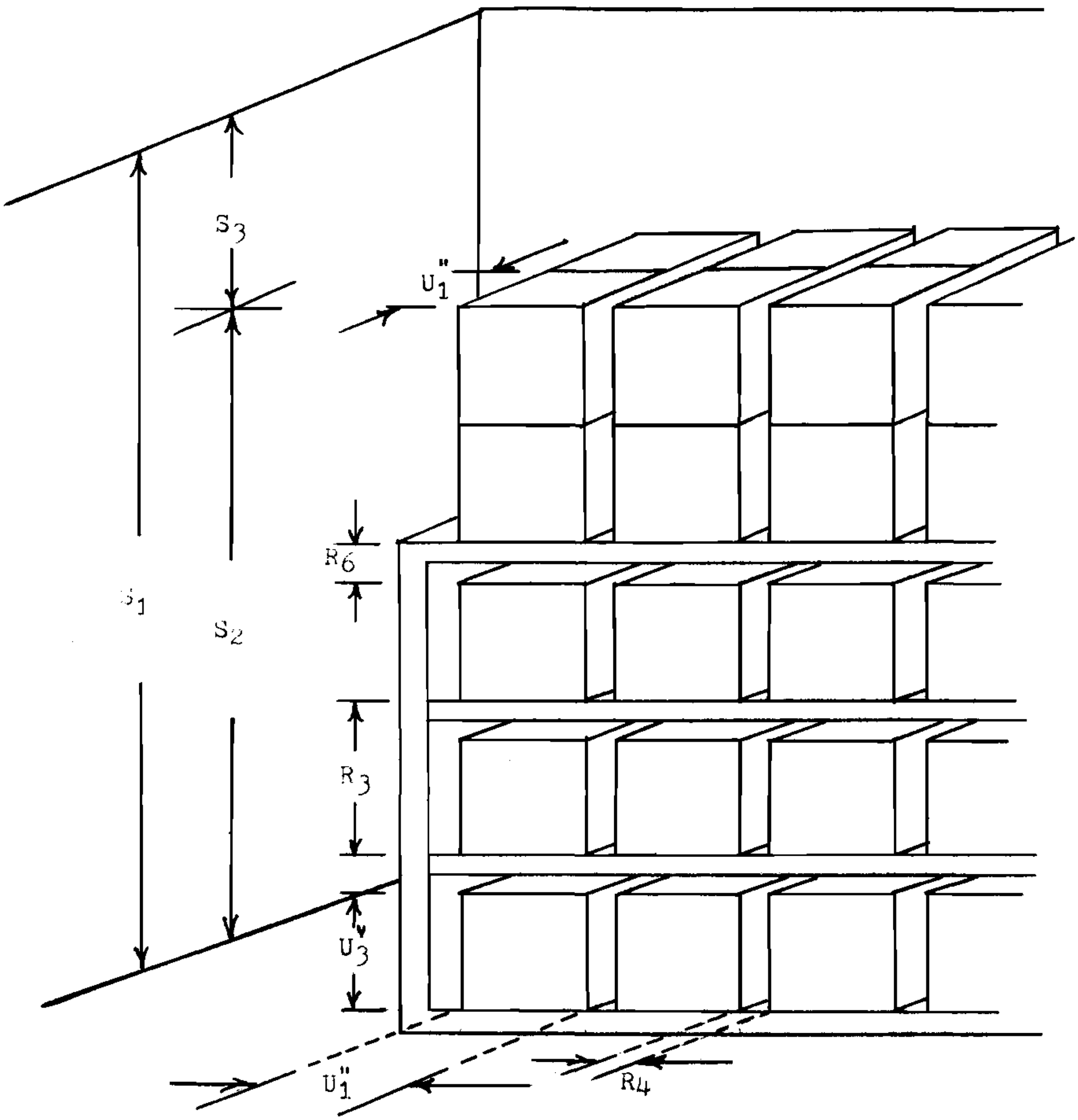

Figure 4-3 Pallet Rack Concept

Clear Headroom: the distance from the floor to the lowest overhead obstruction.

Working Clearance: the space allowed between the top of a stack or column and the lowest overhead obstruction; such as ceiling joists, beams, sprinkler heads, or steam pipes. This allowance will depend upon local fire codes.

Vertical Separations: space consumed by unit clearances between columns, stacks, posts, walls or other warehousing elements.

Horizontal Separations: space consumed by pallets in a column or unit clearances in racks, bins and shelves. Also space consumed by beams, rails, shelves or other horizontal supports.

Cube Utilization: the ratio determined by counting the total cubic feet of materials stored in the warehouse and expressed as a percentage of the total cubic capacity of the warehouse.

Slot: the position in a block occupied by a lot.

Fixed Slot: a slot reserved for a specific stockkeeping unit.

Floating Slot: a slot that becomes available for any stockkeeping unit as soon as it is empty.

Rack Slot: the position occupied by a warehousing unit in the rack. The slot may be one or more units high or one or more units deep. Rack slots may be fixed or floating. Fixed slots are usually located at the first and second level, but all slots can be fixed slots.

Unit Clearance: space allowed for handling clearance between columns or stacks, or between tiers in racks, shelves or bins.

Warehousing Unit: this may be single large package handled as a unit load or a group of packages on a pallet or otherwise utilized.

In this study the following notations will be used: (9)

A = aisle width

E_5 = maximum stacking height of lift truck

G_d = number of loads in depth from the aisle

G_w = number of loads facing the aisle

G_h = number of loads in height from bottom

R_1 = slot depth, including unit load clearances and one-half of aisle width

R_2 = slot width, including load clearance between slots

R_3 = slot height, including load horizontal clearance

R_4 = unit load clearance between rows in the slot

R_5 = unit load clearance between rows in the slot

R_6 = horizontal clearance consumed by unit clearance in racks and other horizontal supports

S_1 = clear headroom

S_2 = working headroom

S_3 = working clearance

U_1'' = maximum allowable length of a unit load

U_2'' = maximum allowable width of a unit load

U_3'' = maximum allowable height of a unit load

Thus, applying the above notation to Figure 4-8, if $[(G_h - 2)R_3 + U_3' > E_5 > (G_h - 2)R_3]$, one may obtain S_1 as follows:

$$R_3 = U_3' + R_6 \tag{21}$$

$$S_2 = R_3(G_h - 2) + 2U_3' \tag{22}$$

so

$$S_2 = (U_3' + R_6)(G_h - 2) + 2U_3'$$

$$= (U_3' + R_6) G_h - 2R_6 \tag{23}$$

Since

$$S_1 = S_2 + S_3 \tag{24}$$

Substitution of equation (23) in equation (24) yields

$$S_1 = (U_3' - R_6)\, G_h - 2R_6 - S_3 \tag{25}$$

In equation (25), it is demonstrated that if U_3', R_6 and S_3 are constant, then S_1 increases as G_h increases. If it is assumed that the working clearance set by local regulations is twelve inches (S_3 - 12") and the horizontal clearance is five inches (R_6 - 5"), then for each different value of U_3' and G_h, the S_1 value can be found by using Table 4-5.

Applying the Approach to the Unit Load Relationship to Packing Containers and Product Containers

In Figure 4-1, after the standard unit load size has been determined, it is necessary to study the size of the packing or product container. This is further emphasized by the fact that world current interest is centered around the "package module" (10). As a simplified definition, the standard package module may be expressed as "standard base area."

The standard unit load sizes having already been derived, the module package sizes can be developed by a simple mathematical relationship. The purpose of defining the standard package module is to find a method by which various package sizes would fit together to form a perfect unit load without any wasted space. In other words, by multiplying or dividing any integer (1, 2, 3, 4, 5, etc.), the dimensions of transport packages or unit loads can be obtained.

As shown in Figure 4-9, if the standard base area of a packing container is defined as 15" x 18" (380 x 450 mm.), then each standard

Table 4-5. Clear Headroom Value With

$S_3 = 12''$, $R_6 = 5''$

G_h \ U_3'	30"	40"	45"	60"
3	9'	11'	12'	16'
4	11'	15'	16'	21'
5	14'	19'	21'	27'
6	17'	22'	25'	32'
7	20'	26'	29'	38'

unit load can be formed perfectly from it (as in Figure 4-10). Once more it is necessary to point out that the height of unit load will depend upon the volume and weight of the load. Yet, the maximum use should be made of container height if density of product allows.

Starting with the modular case size, the sub-divisions of distribution pack size will be determined as shown in Figure 4-11. The above calculation is merely one example of an approach to this problem. For example, the determination of the standard base area might be done by using preferred numbers.

In Chapter VI, the use of preferred numbers is recommended for the sizing of individual product containers. Therefore, in order to get high space utilization in packing containers, various pallet patterns for stacking product containers will be necessary. However, this study will not present research on pallet patterns. The advantages or disadvantages of establishing a standard package module should be studied from the viewpoint of judging its practicality or impracticality. Below is a list of advantages adapted from several sources.

1. A worldwide packaging-distribution system could become possible through standard package modules.
2. Many carton and case manufacturers would be eager to see standard sizes adopted.
3. Less effort and time would be needed to arrange the packages on the pallets.
4. High unit load utilization would be often achieved.
5. Standard package modules would allow simplification of differentiation between assorted consignments for one destination and would simplify methods of handling.
6. Good stacking patterns and stable loads would be formed by standard package modules.

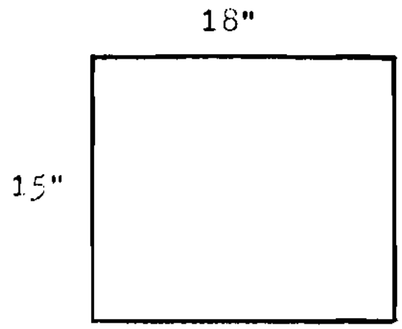

Figure 4-9 Standard Base Area

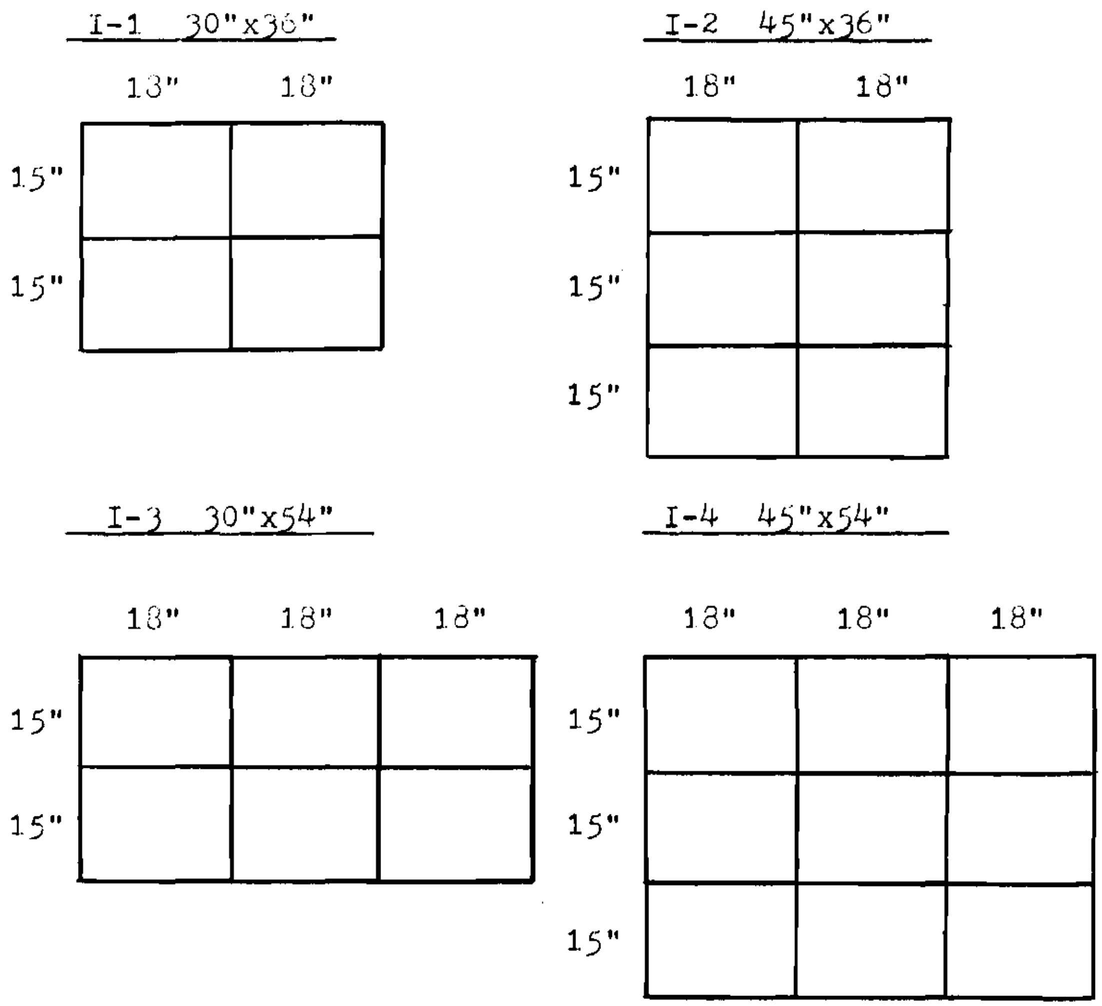

Figure 4-10. Possible Pallet Pattern using S.B.A. Concept on Selected Pallet Sizes.

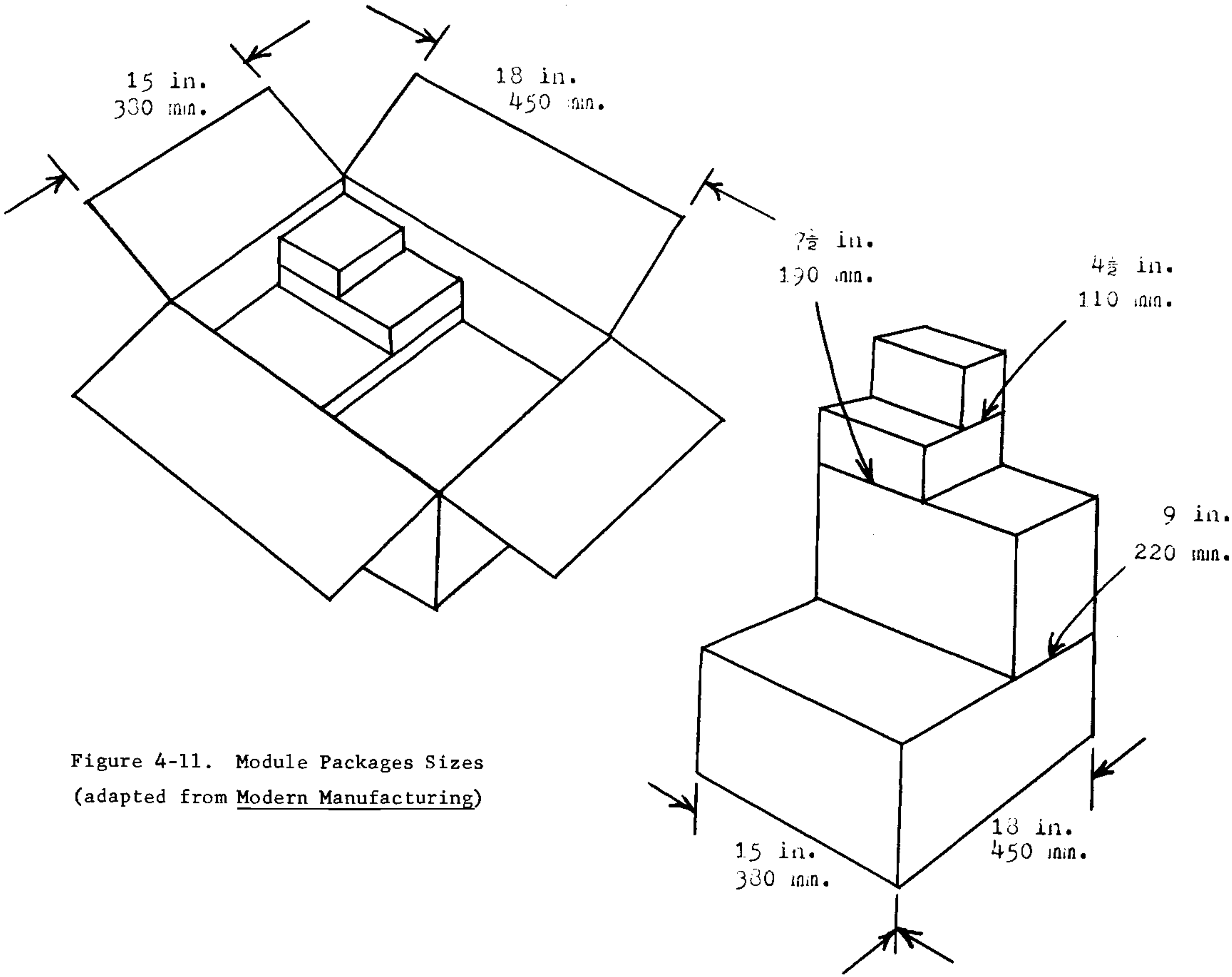

Figure 4-11. Module Packages Sizes
(adapted from Modern Manufacturing)

7. In cold storage, the module pack size would be very important in achieving optimum space utilization.
8. Standardizing the package modules would have worthwhile potential impact right down to the plant level, where unit loads are assembled and stored.
9. For international shipment, it would be necessary to define standardized base areas, so that the most efficient utilization of available space in various transport vehicles could be achieved.

However, there are also several disadvantages that might be argued by companies as reasons for not adopting these proposals:

1. One often finds that manufacturers prefer a case size which fits product line rather than pallet.
2. Some of the restrictions imposed by suppliers may prohibit a company from standardizing packages sizes in relation to unit load size.
3. Because there is a multiplicity of stacking patterns available and because of the possible continuing proliferation of pallet sizes, it is not necessary to standardize the package size.
4. The demands of the customer are always a major problem in considering standardization.
5. The size of the package is often governed by retail sales which is frequently in multiples of dozens, or in weight units.

Summary of Approach

In an attempt to summarize the work to this point, Figure 4-12 outlines the suggested procedure for choosing correct dimensions in the handling/storage/distribution system. It suggests the steps in the procedure as well as the two approaches discussed in this research. Because of time limitations, this study has only mentioned or briefly touched those areas represented by dotted lines. Finally, on the basis of Figure 4-12, it is suggested that future study might investigate a way

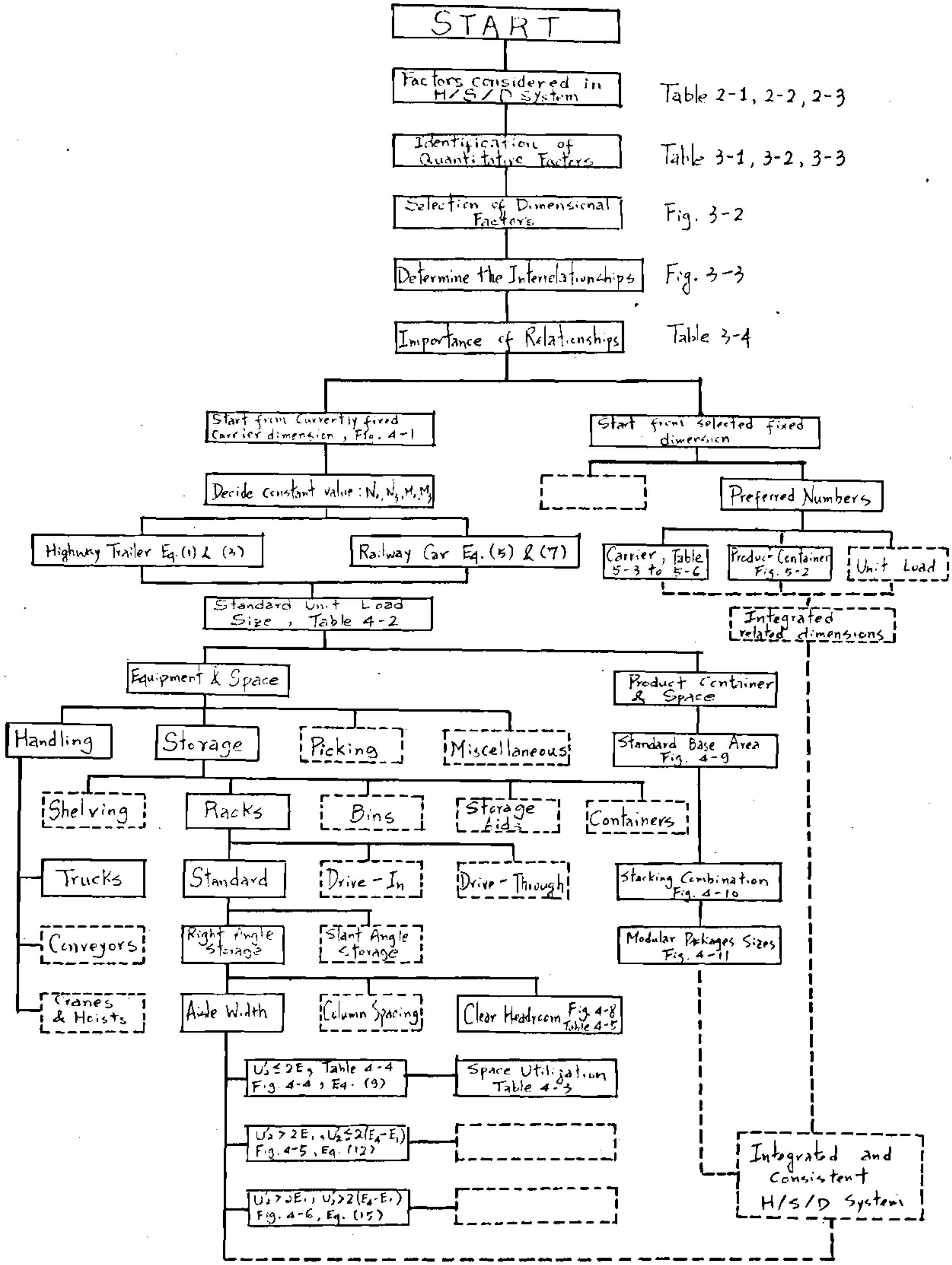

Figure 4-12 Summary Approach for Choosing the Correct Dimensions

to link all the items toward establishing an integrated and consistent handling/storage/distribution dimensional system.

After having determined the interrelationships and rating their importance, refer to the left side of Figure 4-12, which suggests that it might be logical to start from currently fixed interior carrier dimensions, since highway and railway systems have the largest number of fixed dimensions, as previously pointed out. On the right side of Figure 4-12, the other alternative is to start from nothing and establish a whole new dimensional system based on theoretical methodology. For instance, the preferred numbers series might be a good basis for establishing such a system. This possibility will be discussed in the next chapter.

Based on the fixed carrier dimensions, the standardized unit load sizes could be derived, as shown in Figure 4-12. The next two categories are (1) the equipment and space and (2) the product container and space, which should be considered at this time. Equipment can be categorized as storage, handling, picking and miscellaneous. Storage equipment can be further subdivided into racks, shelving, bins, storage aids, and containers (4). Likewise, racks can be further classified as drive-in, drive-through, and standard racks. In the right angle storage category, three situations are presented by equations and figures. Actually, for each individual specific problem the analyst should go further detail, as far as is required.

In studying the product container and space category, the first and most important step is to determine the standard base area, which defines the pallet pattern for stacking unit loads.

CHAPTER V

SIZING OF CONTAINERS FOR CONSUMER PRODUCTS

Since potential standard unit load sizes have already been derived, the standard package modular can be defined by them through a simple mathematical relationship. The problem now is how to determine the container size for small consumer products based on the size of the package modular.

There have been many attempts to solve this problem, but the outcome is quite pessimistic because of the wide variety of products and the relatively low relationships between many products and "useful" container sizes for any one product. So, instead of attacking this problem from the unit load viewpoint, it might be wiser to determine the sizes of smaller consumer containers first, and then to use some pattern to link the unit load or shipping package modular and small package modular. In order to do so, it is necessary to find a tool that can be used to determine a proper series of sizes for small product containers.

When designing a consumer product container, the problem always arises as to what the size should be. Almost inevitably, the manufacturer will have to counter with the user about the size problem. The customer would prefer a choice of more sizes but the manufacturer, on the other hand, would prefer to make and stock the minimum variety of sizes. In other words, the number of different sizes will have to be a compromise between the two.

Since the customer does not like to buy a container that is much too large or too small for his requirements, then the manufacturer's problem may be formulated as follows: What is the minimum number of different sizes that can be produced in order to satisfy customer needs? To answer this question, each case must be based on its own characteristics. For example, if a food processor plans to market a series of packages with sizes ranging from $2\frac{1}{2}$ x 4 x 8 inches (64 x 100 x 200 mm) to 4 x 5 x 10 inches (100 x 130 x 250 mm), inclusive, then what number and variety of sizes should be adopted between them.

Preferred Numbers

Many articles have been written explaining the use of preferred numbers as a tool for determining or standardizing product sizes. But the size is frequently determined entirely by utility or use value (11), such as for wire nails, bolts, wrought-iron pipe, sleeve-bearings, test sieves, etc.

Yet, there appears to be both a need and a trend toward expanding the use of preferred numbers as factors in designing container sizes. These sizes should be determined by "appearance" as well as utility--for example, the sizes of cereal packages, canned food, instant coffee, soft drinks, powdered milk, cookies, crackers, etc.

As pointed out by American Standards Association, "The term SIZE as used here should be interpreted very broadly. While in many cases it will refer to a dimension of length, area or volume, it may also refer to a weight, a capacity to perform, a rating, etc." (12)

Instead of allowing sales departments or advertising agencies arbitrarily to specify the sizes of product containers, engineering-minded people should deal with the problem of developing dimensions that will fit both present and future demands and needs. Also, preferred numbers may be introduced to assist the manufacturer in establishing proper balance and arrangement of item-dimensions in the production line. This will solve future difficulties when standardization may become necessary.

U. S. National Bureau of Standards, for example, is continually adding more and more products to the list of "standard quantity" items. The Federal Government's "Fair Packaging and Labeling Act" requests food and drink manufacturers to reduce the number of consumer container sizes for any given product. In dry breakfast foods, for example, the number has been cut from 33 to 16; for cookies and crackers, the number has been trimmed from 22 to 14. Table 5-1 is the official list, updated to March 1, 1969 (13).

Basic Theory of Preferred Numbers

In order to introduce the theory of Preferred Numbers, the following succession terms shows part of a geometric series:

a, 3a, 9a, 27a, 81a, 243a, etc. This kind of series can be written symbolically, as

$$a,\ ra,\ r^2a,\ r^3a,\ \ldots,\ r^{n-1}a$$

in which

a = first term of the series or the number on which the series is built

r = ratio of each term to the preceding term

and

n = the number of the terms in the series.

Table 5-2 (12), recommended by the American Standard Association, has the same basic relationship as implied above. In the first column,

Table 5-1. Results of Efforts to Standardize the Number of Consumer Package Sizes

Product	*Standard Quantities*	*From*	*To*	*Reduction*	*Effective Date*
Dry breakfast cereals (except individual servings)	Packaged in whole ounces only—no fractional ounces	33	16	52%	Jan. 1, '69
Cheese low-moisture mozzarella provolone cream brick & munster pasteurized process cheese	0-4 oz packages = no limits 4-12 oz packages = 1 oz increments 12-24 oz packages = 4 oz increments (except 13¼ oz) 24-48 oz packages = 8 oz increments	22	14	27%	July 1, '69 (estimated)
Cookies & crackers	0-8 oz packages = 1/4 oz increments 8-16 oz packages = 1/2 oz increments Over 16 oz packages = 1 oz increments	73	56	23%	Jan. 1, '69
Green olives	0-4 oz packages = 1/2 oz increments 4-10 oz packages = 1 oz increments 10-16 oz packages = 2 oz increments Over 16 oz packages = 21 oz increments	50	20	60%	July 1, '69 (estimated)
Instant coffee	2, 4, 6, 8, 10, 12, 14, and 16 oz	10	8	20%	Jan. 1, '69
Instant potatoes	0-4 oz packages = 1/4 oz increments 4-8 oz packages = 1/2 oz increments 8-16 oz packages = 1 oz increments 16-32 oz packages = 4 oz increments Over 32 oz packages = 8 oz increments Servings to be standardized at 4 oz	*	*	*	July 1, '69 (estimated)
Jellies & preserves	10, 12, 16, 18, 20, 24, 28, 32, 48, and 64 oz	16	10	37%	In effect
Macaroni products	0-8 oz packages = 1 oz increments 8-16 oz packages = 2 oz increments 16-32 oz packages = 4 oz increments Over 32 oz packages = 1 lb increments	32	16	50%	July 1, '69
Mayonnaise & salad dressing	(spoon type) 8, 16, 24, and 32 oz (pouring type) 8, 10, 12, 16, and 32 oz	5 7	4 5	20% 29%	In effect
Peanut butter	6, 8, 12, 16, 18, 24, 28, 32, 40, 48, 64, and 80	30	12	59%	In effect
Pickles	whole ounces	*	*	35%	In effect
Potato chips	2-8 oz packages = 1/4 oz increments 8-12 oz packages = 1/2 oz increments 12-20 oz packages = 1 oz increments Over 20 oz packages = 4 oz increments	*	*	33%	July 1, '69
Powdered milk	3, 4, 5, 8, 10, 12, 14, and 20 qt	11	8	27%	July 1, '69 (est'd.)
Salad & cooking oils	12, 16, 24, 32, 38, 48, and 128 oz	15	7	53%	Jan. 1, '69
School paste	2, 4, 8, 16, 32, and 128 oz	*	6	*	
Soft drinks (individual and multi-unit packages)	(individual units) 6, 6½, 7, 8, 10, 12, 16, 24, 26, 28, 30, and 32 oz (2 unit cartons) 48, 52, 56, 60, and 64 oz (3 unit cartons) 72, 78, 84, 90, and 96 oz (4 unit cartons) 64, 96, 104, 112, 120, 128 oz (6 unit cartons) 36, 39, 42, 48, 60, 72, and 96 oz (8 unit cartons) 48, 52, 56, 64, 80, and 128 oz (10 unit cartons) 60, 65, 70, 80, 100, 120, and 160 oz (12 unit cartons) 72, 78, 84, 96, 120, 144, and 192 oz	*	*	33%	July 1, '69
Syrups	Packaged in quantities divisible by 4 oz	*	*	20%	

*No survey made. Percentages shown indicate estimates only.

Table 5-2

BASIC PREFERRED NUMBERS—DECIMAL SERIES (10 to 100)

5-Series (60% Steps)	10-Series (25% Steps)	20-Series (12% Steps)	40-Series (6% Steps)
10	10	10	10
			10.6
		11.2	11.2
			11.8
	12.5	12.5	12.5
			13.2
		14	14
			15
16	16	16	16
			17
		18	18
			19
	20	20	20
			21.2
		22.4	22.4
			23.6
25	25	25	25
			26.5
		28	28
			30
	31.5	31.5	31.5
			33.5
		35.5	35.5
			37.5
40	40	40	40
			42.5
		45	45
			47.5
	50	50	50
			53
		56	56
			60
63	63	63	63
			67
		71	71
			75
	80	80	80
			85
		90	90
			95

Preferred Numbers below 10 are formed by dividing the numbers between 10 and 100 by 10, 100, etc.

Preferred Numbers above 100 are formed by multiplying the numbers between 10 and 100 by 10, 100, etc.

Percentage steps in headings are approximate averages.

the series has been obtained by establishing five steps between 10 and 100, all increasing by the same ratio. If this ratio is r, then from the equation, $10r^5 = 100$, it can be found that $r = \sqrt[5]{10}$ = approximately 1.5849. Using this same method will also yield values for the 5-series: 10, 15.849, 25.119, 39.811, 63.096, and 100. For practical use, the "theoretical" values have been rounded to: 10, 16, 25, 40, 63, and 100. Each of them has a constant step-up of 60 percent. For 10-series, there are twice as many steps in the same range, and a step-up of about 25 percent. If the user desires more steps in the range, there are the 20-series (step-up about 12 percent) and the 40-series (step-up about 6 percent).

The four series in Table 5-2 are called the "Basic Preferred Numbers Series." In addition to these four basic series, the designer may even use the 80-series if necessary, with a step-up of about 3 percent. There are many other series that could be obtained simply by introducing more steps in a basic series. For example, by taking every other step in 5-series (5/2-series), the step-up becomes about 150 percent, and by taking every third step in the 5-series (5/3-series), the step-up becomes about 300 percent.

A.S.A. Standard No. Z17.1-1959 contains tables giving preferred numbers in binary fractions up to 40, in the 5-, 10-, 20-, 40-, and 80-series. These numbers are recommended only for linear dimensions in inches where binary fractions are in common use. This table is given in the appendix.

Determining the Sizes by Using Preferred Numbers

As the name "preferred numbers" indicates, the designer is asked to use these numbers in preference to any other number series.

The application of preferred numbers can be simplified by using a graph called "prenograph" (14) as shown in Figure 5-1. This graph is based on the fact that preferred numbers series step-up on a constant ratio. In other words, their logarithms step-up by a constant value, for logarithms of 5-series, range 1.0 to 2.0, are 0.2. In Figure 5-1, on the vertical axis, the logarithms of the number of the 5- and 10-series is shown only from 10 to 31.5 and from 10 to 18. The characteristic of this graph is the difference between the slopes corresponding to each step-up. Thus, the slope of the 5-series graph (60 percent step-up) is greater than the 10-series (25 percent step-up).

The first step for the designer is to determine the smallest and the largest sizes required and the number of intermediate sizes needed. Using the example presented earlier, a food processor plans to market a series of packages with sizes ranging from $2\frac{1}{2}$ x 4 x 8 inches (64 x 100 x 200 mm) to 4 x 5 x 10 inches (100 x 130 x 250 mm), inclusive, and the desired number of sizes in the interval is three. Since fractions are commonly used in food packaging, it would be most practical to check the preferred number in fractional series (Table 5-7 - 1/8 to 40). Suppose when the final decision was made, the sizes of packages are as follows:

Length	Width	Height	Volume
4" (4.0")	$2\frac{1}{2}$" (2.5")	8" (8.0")	80 cu-in. (80 cu-in.)
$4\frac{1}{4}$" (4.25")	2 3/4"(2.8")	$8\frac{1}{2}$" (8.5")	100 cu-in. (101.2 cu-in.)

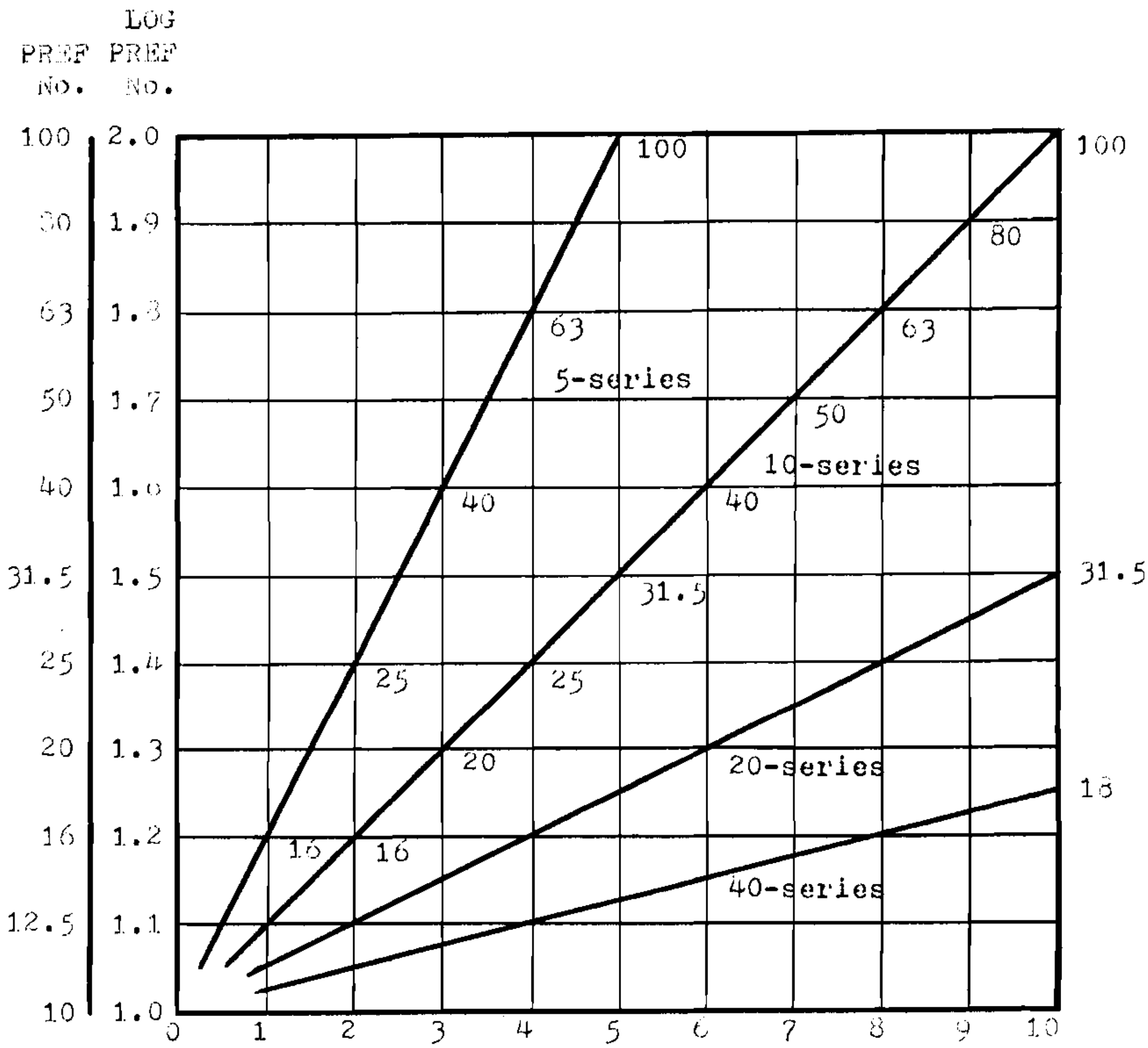

Figure 5-1. Prenograph for Range from 10 to 100

Length	Width	Height	Volume
4½" (4.5")	3" (3.15")	9" (9.0")	120 cu-in.(123.6 cu-in)
4 3/4" (4.75")	3½" (3.55")	9½" (9.5")	160 cu-in.(160.2 cu-in)
5" (5.0")	r" (4.0")	10" (10.0")	200 cu-in.(200.0 cu-in)

We find that the volume also increases in a geometric manner, and its step-up is 25%, as shown symbolically below:

Length	Width	Height	Volume
a	b	c	$abd = k$
ar_1	br_2	cr_3	$(abc)(r_1r_2r_3) = kR$
ar_1^2	br_2^2	cr_3^2	$(abc)(r_1r_2r_3)^2 = kR^2$
ar_1^3	br_2^3	cr_3^3	$(abc)(r_1r_2r_3)^3 = kR^3$

If $r_1 = \sqrt[40]{10}$, $r_2 = \sqrt[30]{10}$, $r_3 = \sqrt[40]{10}$, then $R = r_1r_2r_3 = \sqrt[10]{10}$. Thus, the volume also has a constant ratio R ($R = r_1r_2r_3$) to each preceding one. In Figure 5-2, the prenograph shows the relation and shope of this specific case: just as the value taken from the preferred number table was either rounded off or justified for practical use, the plotting of the graph is simplified considerably by using the "theoretical value" for a clearer explanation.

The Advantages of Using Preferred Numbers

Based on a survey of the literature, the following list of concrete advantages has been developed to support the use of preferred numbers in designing the sizes of product container.

1. As A.S.A. Standard No. Z17.1-1958 recommends, experience has shown that the consumer's requirements are frequently satisfied when the range of sizes follows more or less closely a geometrical progression.
2. Preferred numbers may assist in setting up the proper balance in a product line and can reduce the difficulty if standardization later

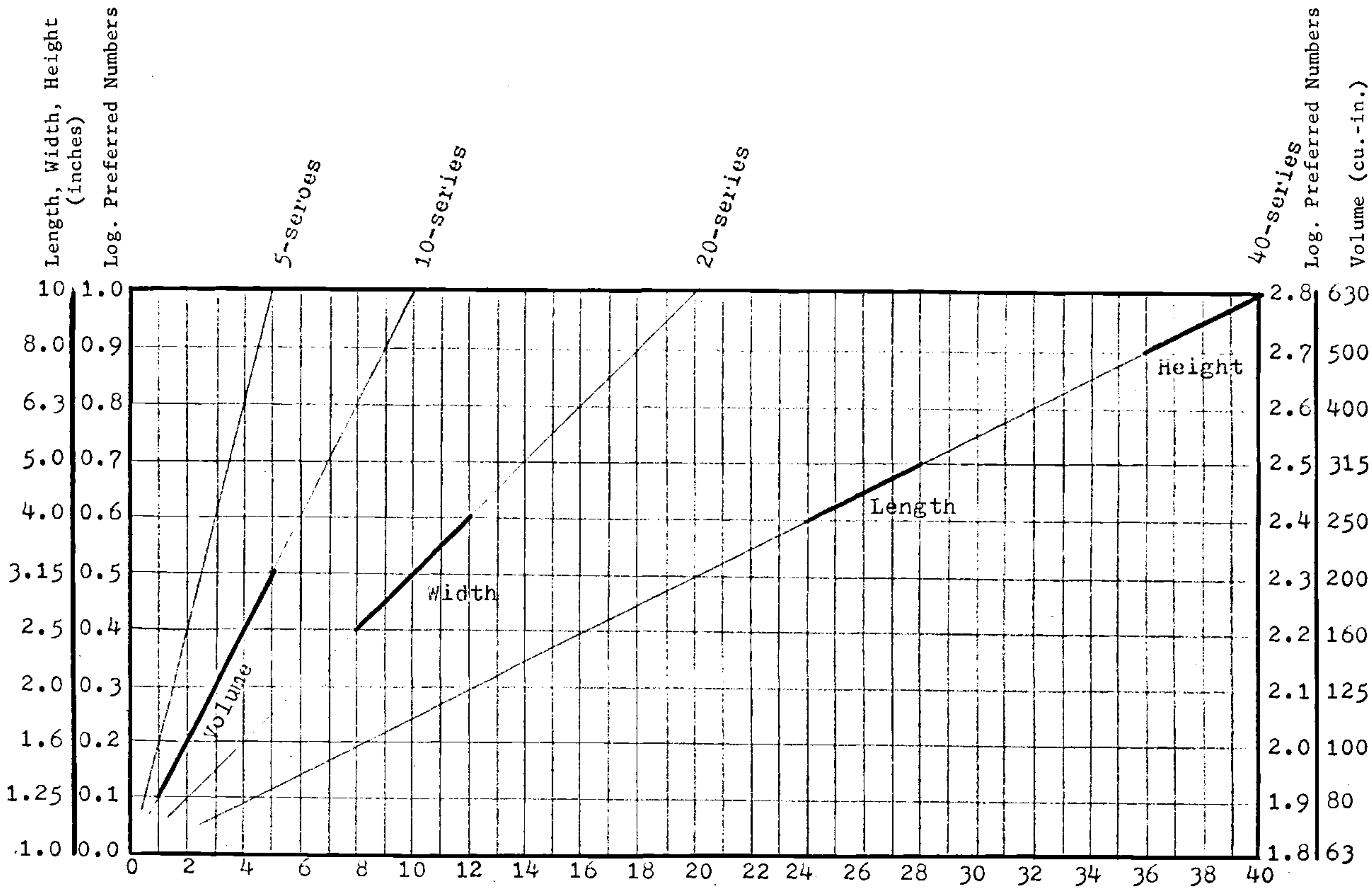

Figure 5-2. Prenograph for Package Dimensions

becomes necessary.

3. If the application is practical, they may yield substantial technical and economic benefits.
4. The application of the theory of geometrical series is simple.
5. Although the values of all series have been slightly rounded from the "theoretical figures," the difference is not greater than 1.3%.
6. Through the basic and additional series, the user is permitted a wide variety of choices, including the binary fractions tables.
7. The application of preferred numbers is independent of the measurement system being used, whether Metric or English. Because the standard conversion ratio between these two systems happens to be 25.4, it differs by only 1.6% from 25, a preferred number. This means that when inch values in preferred numbers are converted to rounded millimeter values, the resulting size will differ from preferred numbers by only about 1.6%.
8. In designing can sizes, the value of (approximately) 3.141 is used, this also is close to a preferred number (3.15). Therefore, if the diameter of a circle is a preferred number, its circumference and its area also are close to preferred numbers.
9. All preferred numbers series have a constant percentage step-up throughout their range.

From the above, it is obvious that preferred numbers is not only a good tool for standardizing product containers but also a proper way to obtain substantial technical and economic benefits.

It is quite reasonable to assume that the use of preferred numbers might be appropriate in establishing a proper dimensional system for the whole handling/storage/distribution cycle. For example, it might be a good idea to use preferred numbers to determine the sizes of carriers, the different sizes of unit loads and even the sizes of storage spaces.

Expanding the Use of Preferred Numbers

Having presented the concept of preferred numbers of the preceding pages, this section will explore the possibility of applying the preferred number concept to the establishment of proper sizes for the various modes of travel and transportation commonly used in the handling/distribution cycle. If it is assumed for the purpose of this thesis that the average automobile has a width of six feet, a truck eight feet, a railroad car ten feet, then it would be possible to apply the preferred number concept to the relationship between the three in an attempt to determine which one should be what size. This should result in a logical interrelationship between sizes rather than an arbitrary one such as the six, eight, ten foot dimensions.

In Tables 5-3 through 5-6 are shown the results of applying the preferred numbers concept to the carrier sizes as previous mentioned. Each of the four tables applies a different series of preferred number's steps to the suggested dimensions. In each application of the preferred number series, the chosen dimension of the vehicle as suggested earlier is held constant and the preceding and succeeding dimensions are derived from the preferred number series chosen. For instance, in Table 5-3, Column A begins with the width of a car established as six feet and the succeeding vehicle widths determined by applying 6% steps to the six feet making the last entry in Column A 7.1 feet for what has been referred to as a "super car." Looking at the four tables again, it will be seen that in some cases the width of the car becomes too wide and the super car too little different in size, as in Column D of Table 5-3.

Tables 5-3 through 5-6
New Carrier Width System

KIND \ SERIES	A	B	C	D
Car	6.0	7.5	9.0	10.1
Truck	6.4	8.0	9.4	10.7
Railroad Car	6.7	8.5	10.0	11.3
Super Car	7.1	9.0	10.6	12.0

(6% steps)

Table 5-3

KIND \ SERIES	A	B	C	D
Car	6.0	7.1	8.0	8.5
Truck	6.7	8.0	9.0	9.6
Railroad Car	7.5	9.0	10.0	10.7
Super Car	8.4	10.0	11.2	12.0

(12% steps)

Table 5-4

KIND \ SERIES	A	B	C	D
Car	6.0	6.4	6.4	6.1
Truck	7.5	8.0	8.0	7.7
Railroad Car	9.4	10.0	10.0	9.6
Super Car	11.7	12.5	12.5	12.0

(25% steps)

Table 5-5

KIND \ SERIES	A	B	C	D
Car	6.0	5.0	3.9	2.9
Truck	9.6	8.0	6.3	4.7
Railroad Car	15.4	12.8	10.0	7.5
Super Car	24.6	20.5	16.0	12.0

(60% steps)

Table 5-6

If carrier sizes were to be determined in this fashion, it would be necessary for the government or some organization to decide which transportation mode should be used as the base. For example, if it were decided to use the railroad as the base, because it has the greatest number of fixed dimensions, such as bridges, tunnels, docks, etc., then it would appear logical to use Table 5-5, where the width of the rail car is held at 10 feet and the other carriers are as follows: automobile, 6.4', truck, 8', and super car, 12.5'.

From the above analysis, it can be easily seen that preferred numbers cannot only be used to determining the sizes of carriers and related containers, but can also establish the basis for dimensions of unit loads, handling equipment, etc. It can be concluded that the preferred number concept could offer many advantages if it were applied to the determination of carrier sizes and then extended to the other dimensional factors in the handling/storage/distribution cycle. This research suggests further investigation into the use of preferred numbers along the lines illustrated here.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In general, it can be concluded that the concepts and equations developed in this study provide a basic tool with which to approach the dimensional aspects of the handling/storage/distribution problem. However, it should be realized that in this study only general cases have been discussed.

Composite tables have been compiled in order to demonstrate that there are many aspects which need to be considered in planning an integrated handling/storage/distribution system. In these tables, factors have been carefully classified and judged as to whether they are tangible, indeterminate or intangible. Also, each factor has been identified as either quantitative or qualitiative. This permits a closer look at the complex interrelationships between factors. However, a more precise judgment and careful analysis is needed at this point, since often the last category of factors to be considered when facing a handling/storage/distribution problem is that of intangible factors. It is known that they are extremely important as well as the most difficult to take into consideration. It is recommended that further research be directed toward determing some way to properly evaluate these factors.

It should be noted that the person who determines the degree of importance of dimensional interrelationships must be highly experienced in this specific field in order to make valid judgments. Although the results of each person's evaluation will be slightly different, it is still possible to ascertain those dimensional factors which will have the greatest effect and provide assistance in dealing with the specific problem.

Because of the approach that has been employed, the sequence for selecting the correct dimensions began with the inside dimensions of the "standardized" carrier. In this study, the term carrier refers to a highway trailer van or railway freight car, but the approach can be expanded to cover air and sea freight problems as well. No consideration has been given to the effect on carrier capacity of the density of unit loads. It would seem practical in continuing this study to take additional and non-dimensional factors into consideration, such as the density of materials and capacity of facilities.

When studying storage space, a right angle stacking aisle width with no clearance between the unit loads has been assumed. No consideration has been given to the length of time a unit load remains in storage and what effect it will have on the depth of storage.

However, it should be pointed out that careful consideration must be given to this point when making the layout. Also in this study, it is not intended to compare slant angle storage and right angle storage, but to prove by the equations, etc., that those factors which have very important relationships to storage space have been properly considered.

From this study, it can be concluded that the compatibility of an international handling/storage/distribution system can be worked out only if the standard base area of the packing container can be defined. This is because each standard unit load can only be formed perfectly from it. The author must point out that decisions concerning the dimensions of any one segment of the system will affect the planning of the entire system. In other words, whenever a size is decided upon, the dimensional interrelationships between factors should always be kept in mind. It is recommended that, before reaching a final decision, the engineer give careful consideration to each dimensional factor that might affect the efficiency of the handling, storage, and distribution cycle.

Finally, the author recommends the consideration of preferred numbers as a tool not only for sizing small product containers but also for determining sizes for unit loads, shipping containers or even carriers. By using preferred numbers, further study is encouraged on integrating each aspect of the cycle in order to establish a consistent, integrated system.

APPENDIX

Table 2-2

Composite List of Tangible Factors
Related to Handling/Storage/Distribution Problems*

Material

1. quantity
2. density
3. number of different parts

Move

1. speed
2. volume
3. distance
4. frequency
5. rate
6. area
7. range
8. load/unload level
9. movement level

Process and Operation

1. reliability
2. number of operations
3. number of sub-assemblies
4. number of different parts

Product Container, Packing Container and Unit Load

1. length
2. width
3. height
4. diameter
5. weight

*Developed from several lists prepared by Professor James M. Apple for use at the Georgia Institute of Technology.

Table 2-2 (Continued)

Product Container, Packing Container and Unit Load (Cont.)

6. items/load
7. tare
8. capacity

Carrier

1. length
2. width
3. height
4. capacity
5. operation clearance
6. structural design

Storage Space

1. column spacing
2. aisle width
3. clear height
4. plant size
5. cost of floor space
6. number of floors
7. space requirements
8. space available
9. total volume of storage
10. storage time
11. floor load capacity
12. overhead load capacity
13. size of door
14. load on the roof
15. load on the trusses, joists, etc.
16. size of elevator

Table 2-2 (Continued)

Storage Equipment

1. dimension of storage slot
2. capacity of storage slot
3. clearance between loads
4. total volume of storage
5. working headroom
6. number of loads in depth from the aisle
7. number of loads facing the aisle
8. storage requirements

Handling Equipment

1. dimensions
2. speed
3. capacity
4. horse power
5. turning radius
6. retracted height
7. maximum speed
8. stacking heights
9. load center
10. performance of handling

Table 2-3

Composite List of Indeterminate Factors
Related to Handling/Storage/Distribution Problems*

Material

1. flowability
2. viscosity
3. compressibility
4. acidity/alkalinity
5. moisture content
6. abrasiveness
7. elevated temperature
8. particle hardness
9. size
10. cohesiveness
11. dusty
12. corrosiveness
13. friability
14. shrinkage
15. evaporation
16. toxicity
17. flamability
18. light sensitivity
19. interlocks, mats, agglomerates
20. generates static electricity
21. particle size
22. physical condition
23. explosiveness
24. contaiminable
25. fragile
26. sturdy
27. perishability

*Developed from several lists prepared by Professor James M. Apple for use at the Georgia Institute of Technology.

Table 2-3 (Continued)

Move

1. scope
2. sequence
3. traffic type
4. traffic direction
5. operations in transit
6. cross-traffic
7. origin and destination
8. movement of personnel
9. location
10. course

Process and Operation

1. type
2. interrelationships
3. specific requirements
4. operation sequence
5. product vs. process layout
6. production control
7. possibility of performing during move

Product Container, Packing Container and Unit Load

1. type
2. shape
3. characteristics
4. stability
5. construction
6. disposal of container
7. pattern

Table 2-3 (Continued)

Carrier

1. type
2. shape
3. characteristics
4. construction material

Storage Space

1. shape of building
2. type of building
3. type of construction
4. location of doors
5. location of columns
6. location of elevator
7. type of columns
8. type of elevator
9. fire regulations
10. type of aisle
11. location of aisle
12. building congestion
13. accessibility to equipment
14. location of receiving and shipping
15. congested areas
16. ramps
17. construction materials

Storage Equipment

1. type of equipment
2. working conditions
3. shape of equipment
4. storage method
5. handling method
6. environmental requirements
7. fixed/floating slot
8. supervisory requirements

Table 2-3 (Continued)

Handling Equipment

1. desired characteristics
2. type
3. operator position
4. motive power
5. auxiliary equipment
6. travel plane
7. supplementary load/unload
8. take-up
9. discharge method
10. feed type
11. idler type
12. tire type
13. belt direction
14. support

Table 2-4

Composite List of Intangible Factors
Related to Handling/Storage/Distribution Problems*

1. durability of equipment
2. compatibility of equipment
3. standardization of equipment and components
4. flexibility
5. adaptability
6. safety
7. obsolescence
8. reputation
9. availability of equipment
10. possible damage to materials
11. possible pilferage in transit and storage
12. possible reduction in insurance rates
13. financial policy
14. labor relations aspects
15. effect on morale
16. plans for expansion
17. improved customer service
18. pride in installation
19. possible use of gravity
20. possible alternatives
21. depreciation policy

*adapted from (4), p. 10-27.

Table 5-7

BASIC PREFERRED NUMBERS—FRACTIONAL SERIES (1/8 to 40)

The use of Preferred Numbers in binary fractions should be restricted to cases where such fractions are in common use and decimal fractions are therefore impractical. Percentage figures in headings are approximate averages.

1/8 to 1				1 to 10				10 to 40			
5-Series (60% Steps)	10-Series (25% Steps)	20-Series (12% Steps)	40-Series (6% Steps)	5-Series (60% Steps)	10-Series (25% Steps)	20-Series (12% Steps)	40-Series (6% Steps)	5-Series (60% Steps)	10-Series (25% Steps)	20-Series (12% Steps)	40-Series (6% Steps)
				1	1	1	1	10	10	10	10
							1 1/16				10 1/2
						1 1/8	1 1/8			11	11
							1 3/16				11 1/2
	1/8	1/8			1 1/4	1 1/4	1 1/4		12	12	12
							1 5/16				13
		9/64				1 3/8	1 3/8			14	14
							1 7/16				15
5/32	5/32	5/32		1 1/2	1 1/2	1 1/2	1 1/2	16	16	16	16
							1 5/8				17
		11/64				1 3/4	1 3/4			18	18
							1 7/8				19
	3/16	3/16	3/16		2	2	2		20	20	20
			13/64				2 1/8				21
		7/32	7/32			2 1/4	2 1/4			22	22
			15/64				2 3/8				23
1/4	1/4	1/4	1/4	2 1/2	2 1/2	2 1/2	2 1/2	24	24	24	24
			17/64				2 5/8				26
		9/32	9/32			2 3/4	2 3/4			28	28
			19/64				2 7/8				30
	5/16	5/16	5/16		3	3	3		32	32	32
			21/64				3 1/4				34
		11/32	11/32			3 1/2	3 1/2			36	36
			23/64				3 3/4				38
3/8	3/8	3/8	3/8	4	4	4	4	40	40	40	40
			13/32				4 1/4				
		7/16	7/16			4 1/2	4 1/2				
			15/32				4 3/4				
	1/2	1/2	1/2		5	5	5				
			17/32				5 1/4				
		9/16	9/16			5 1/2	5 1/2				
			19/32				5 3/4				
5/8	5/8	5/8	5/8	6	6	6	6				
			21/32				6 1/2				
		11/16	11/16			7	7				
			23/32				7 1/2				
	3/4	3/4	3/4		8	8	8				
			13/16				8 1/2				
		7/8	7/8			9	9				
			15/16				9 1/2				

Above 40 the fractional Preferred Numbers are the same as the decimal Preferred Numbers (Table 1).

Below 1/4 the decimal series should be used.

Below 3/16 the steps of the 40-series are omitted, as gradations finer than that of the 20-series will seldom be used.

In order to make the fractional system conform to well-established practices, the selected figures do not conform as closely to the theoretical values as the figures in the decimal system, the discrepancy being as much as 4 to 6% in some cases. The maximum difference between values of the demical and corresponding fractional system is 6.3%.

Table 5-8

Basic Preferred Numbers—Fractional 80-Series (3/8 to 40)

80-Series					Other series in which numbers of 80-series appear			
3/8	1	2 1/2	6	16	40	20	10	5
25/64	1 1/32	2 9/16	6 1/4	16 1/2				
13/32	1 1/16	2 5/8	6 1/2	17	40			
27/64	1 3/32	2 11/16	6 3/4	17 1/2				
7/16	1 1/8	2 3/4	7	18	40	20		
29/64	1 5/32	2 13/16	7 1/4	18 1/2				
15/32	1 3/16	2 7/8	7 1/2	19	40			
31/64	1 7/32	2 15/16	7 3/4	19 1/2				
1/2	1 1/4	3	8	20	40	20	10	
33/64	1 9/32	3 1/8	8 1/4	20 1/2				
17/32	1 5/16	3 1/4	8 1/2	21	40			
35/64	1 11/32	3 3/8	8 3/4	21 1/2				
9/16	1 3/8	3 1/2	9	22	40	20		
37/64	1 13/32	3 5/8	9 1/4	22 1/2				
19/32	1 7/16	3 3/4	9 1/2	23	40			
39/64	1 15/32	3 7/8	9 3/4	23 1/2				
5/8	1 1/2	4	10	24	40	20	10	5
41/64	1 9/16	4 1/8	10 1/4	25				
21/32	1 5/8	4 1/4	10 1/2	26	40			
43/64	1 11/16	4 3/8	10 3/4	27				
11/16	1 3/4	4 1/2	11	28	40	20		
45/64	1 13/16	4 5/8	11 1/4	29				
23/32	1 7/8	4 3/4	11 1/2	30	40			
47/64	1 15/16	4 7/8	11 3/4	31				
3/4	2	5	12	32	40	20	10	
25/32	2 1/16	5 1/8	12 1/2	33				
13/16	2 1/8	5 1/4	13	34	40			
27/32	2 3/16	5 3/8	13 1/2	35				
7/8	2 1/4	5 1/2	14	36	40	20		
29/32	2 5/16	5 5/8	14 1/2	37				
15/16	2 3/8	5 3/4	15	38	40			
31/32	2 7/16	5 7/8	15 1/2	39				
				40	40	20	10	5

Although there are few applications requiring steps smaller than the 6% steps of the 40-series, such applications may occur. Therefore, an 80-series, both decimal and fractional, has been adopted (Tables 3 and 4).

The numbers of this series should also be useful in many cases where it is necessary to standardize two values that should be rather close together and where a difference of 3% is suitable. One of the values can be chosen from one of the coarser series and the other can be the value of the 80-series immediately following.

Steps between numbers in Tables 3 and 4 increase on an average of approximately 3%.

Table 5-9

Basic Preferred Numbers—Decimal 80-Series (10 to 100)

80-Series	Other series in which numbers of 80-series appear			
10	40	20	10	5
10.3				
10.6	40			
10.9				
11.2	40	20		
11.5				
11.8	40			
12.1				
12.5	40	20	10	
12.8				
13.2	40			
13.6				
14	40	20		
14.5				
15	40			
15.5				
16	40	20	10	5
16.5				
17	40			
17.5				
18	40	20		
18.5				
19	40			
19.5				
20	40	20	10	
20.6				
21.2	40			
21.8				
22.4	40	20		
23				
23.6	40			
24.3				
25	40	20	10	5
25.7				
26.5	40			
27.2				
28	40	20		
29				
30	40			
30.7				
31.5	40	20	10	
32.5				
33.5	40			
34.5				
35.5	40	20		
36.5				
37.5	40			
38.7				
40	40	20	10	5
41.2				
42.5	40			
43.7				
45	40	20		
46.2				
47.5	40			
48.7				
50	40	20	10	
51.5				
53	40			
54.5				
56	40	20		
58				
60	40			
61.5				
63	40	20	10	5
65				
67	40			
69				
71	40	20		
73				
75	40			
77.5				
80	40	20	10	
82.5				
85	40			
87.5				
90	40	20		
92.5				
95	40			
97.5				

Although there are few applications requiring steps smaller than the 6% steps of the 40-series, such applications may occur. Therefore an 80-series, both decimal and fractional, has been adopted (Tables 3 and 4).

The numbers of this series should also be useful in many cases where it is necessary to standardize two values that should be rather close together and where a difference of 3% is suitable. One of the values can be chosen from one of the coarser series and the other can be the value of the 80-series immediately following.

Steps between numbers in Tables 3 and 4 increase on an average of approximately 3%.

Table 5-10

Decimal Series (1 to 1000)

5/2 Series (150% Steps)	5/3 Series (300% Steps)	10/3 Series (100% Steps)	20/3 Series (40% Steps)	40/3 Series (18% Steps)
1	1	1	1	1
				1.18
			1.4	1.4
				1.7
		2	2	2
				2.36
2.5				
			2.8	2.8
				3.35
	4	4	4	4
				4.75
			5.6	5.6
6.3				
				6.7
		8	8	8
				9.5
			11.2	11.2
				13.2
16	16	16	16	16
				19
			22.4	22.4
				26.5
		31.5	31.5	31.5
				37.5
40				
			45	45
				53
	63	63	63	63
				75
			90	90
100				
				106
		125	125	125
				150
			180	180
				212
250	250	250	250	250
				300
			355	355
				425
		500	500	500
				600
630				
			710	710
				850

Preferred Numbers below 1 are formed by dividing the numbers between 1 and 1000 by 1000.

Preferred Numbers above 1000 are formed by multiplying the numbers between 1 and 1000 by 1000.

Table 5-11

Fractional Series (1/8 to 40)

5/2 Series (150% Steps)	5/3 Series (300% Steps)	10/3 Series (100% Steps)	20/3 Series (40% Steps)	40/3 Series (18% Steps)
		1/8	1/8	
5/32				
			11/64	
				13/64
	1/4	1/4	1/4	1/4
				19/64
			11/32	11/32
5/8				
				13/32
		1/2	1/2	1/2
				19/32
			11/16	11/16
				13/16
1	1	1	1	1
				1 3/16
			1 3/8	1 3/8
				1 5/8
		2	2	2
				2 3/8
2 1/2				
			2 3/4	2 3/4
				3 1/4
	4	4	4	4
				4 3/4
			5 1/2	5 1/2
6				
				6 1/2
		8	8	8
				9 1/2
			11	11
				13
16	16	16	16	16
				19
			22	22
				26
		32	32	32
				38
40				

Supplementary series are selected from the basic series and are used where percentage steps above 60, or between 60 and 25 or 25 and 12 are necessary for some justifiable reason.

Where it is desirable to have a 9% increase in steps, such a series may be constructed by using every 3rd step in the 80-series.

Percentage figures in headings are approximate averages.

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